ARRA Site Characterization Projects

Characterization of Most Promising Carbon Capture and Sequestration Formations in the Central Rocky Mountain Region (RMCCS)

Acknowledgements I

• Many thanks to the U.S. Department of Energy and NETL for supporting this project

• We express our gratitude also to our many industry partners, who have committed a great deal of time, funding and other general support for this project

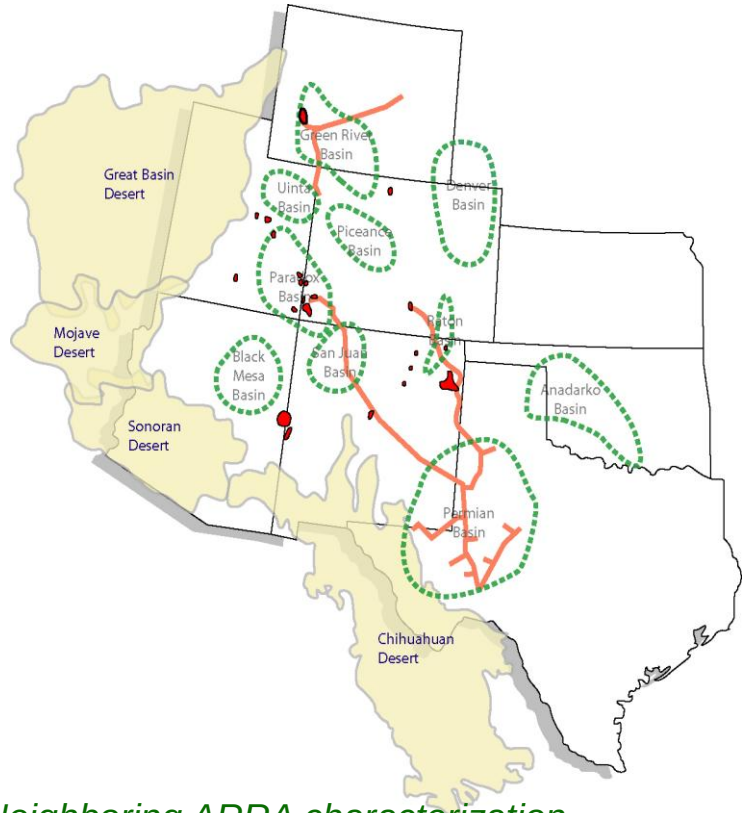
• The work presented today is co-authored by many partners in the RMCCS project

Presentation Outline

- Project Team (Who)
- Major Goals (Why)
- Work Plan (How)
- Progress to Date (What)

Partners

The project team consists of the geological surveys in each state of the region, some invaluable industry partners, and of course NETL.



Neighboring ARRA characterization projects in Wyoming and Kansas will also be essential partners.

Colorado Geological Survey

Southwest Carbon Partnership

The University of Utah™

Utah Geological Survey

Schlumberger

Arizona Geological Survey

Shell

TRI-STATE Generation and Transmission Association, Inc.

NETL

New Mexico Bureau of Geology and Mineral Resources

Acknowledgements II

Tri-State Generation and Transmission- $300K

Shell Exploration & Production- $200K

Schlumberger Carbon Management- $1.3M

Colorado Geological Survey- $162K

University of Utah - $125K

Utah Geological Survey- $22K

Arizona Geological Survey- $19K

New Mexico Bureau of Geology $19K

Presentation Outline

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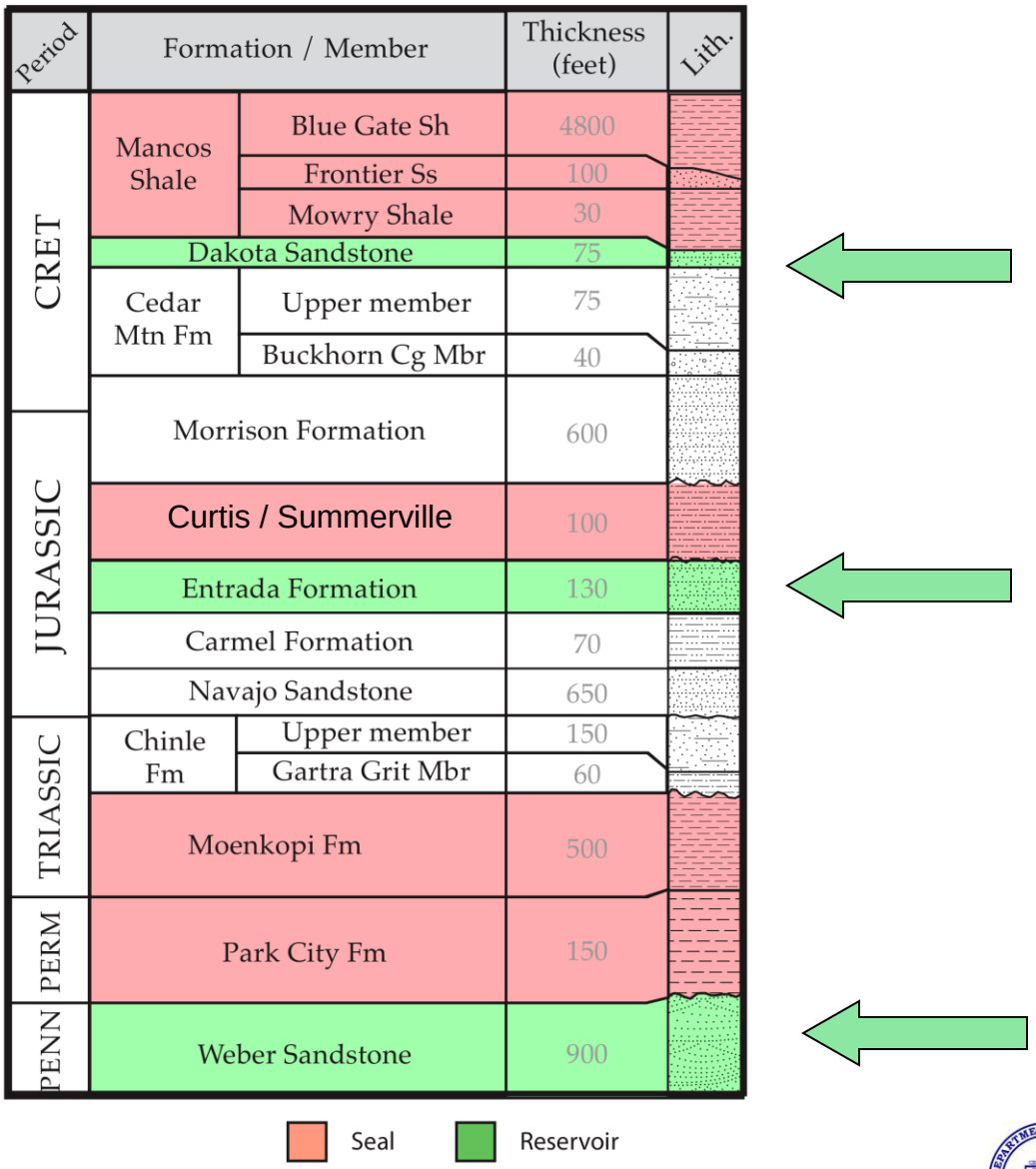
Major Goals and Context

Major Goals:

I. ***Effectively characterize*** the most promising geologic storage targets in the Rocky Mountain region

II. Develop an ***effective protocol*** for characterization and site selection



Major Goals and Context

Specific Goals:

(1) optimization of **capacity estimation**

(2) optimization of **monitoring design** - especially effective spatial coverage and survey/measurement frequency

(3) optimization of **simulation models** - especially alignment of spatial and temporal scales of models with those of monitoring technologies

(4) optimization of **risk assessment**

We anticipate that explicit focus on improving characterization methodologies can create major improvements of these four critical CCS activities.

Expected Outcomes

First and foremost, the deliverables:

Task 1.0 Project Management

- Updated Project Management Plan
- NEPA and permitting
- Education and Outreach begins
- **Copies of all permits**, including summary topical report of acquisition protocols

Task 2.0 Assess Regional Significance of the Dakota, Entrada, and Weber Formations

- Gather all available data, esp. but not limited to public information
- Regional Models and Analyses
- **Evaluate Regional Capacity and Significance** (Topical Report)
- **Update national databases**

Task 3.0 Site-Specific Evaluation of the Dakota, Entrada, and Weber Formations

- Drill, Log and Core Deep Well
- Evaluate Sequestration Capacity of Most Promising Formations (Topical Report)
- Simulation Model Analysis of Most Promising Formations (Topical Report)

Task 4.0 Conduct Risk Assessment

- Risk Registry for Case Study Site
- Develop Risk Assessment and Mitigation Strategies (Topical Report)

Task 5.0 Final Site Characterization Plan and Protocols

- Finalize Characterization of Most Promising CCS Geologic Formations (Topical Report)
- **Final Site Characterization Plan and Protocols Document**

Task 6.0 Develop a well bore management and mitigation strategy

- Same deliverables as listed under task 4

Task 7.0 Optimize Reservoir Engineering to Maximize CO_2 Injection/Produced Fluid Beneficial Use

- Develop and Report on Reservoir Engineering Optimization Strategies (Topical Report)

Expected Outcomes

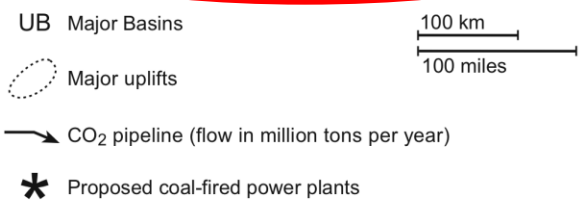
Optimize Capacity Estimation: Number of Years for Specific Sources

Annual mass of CO_2 emissions from power plants, in million tons per year (Mt/y)

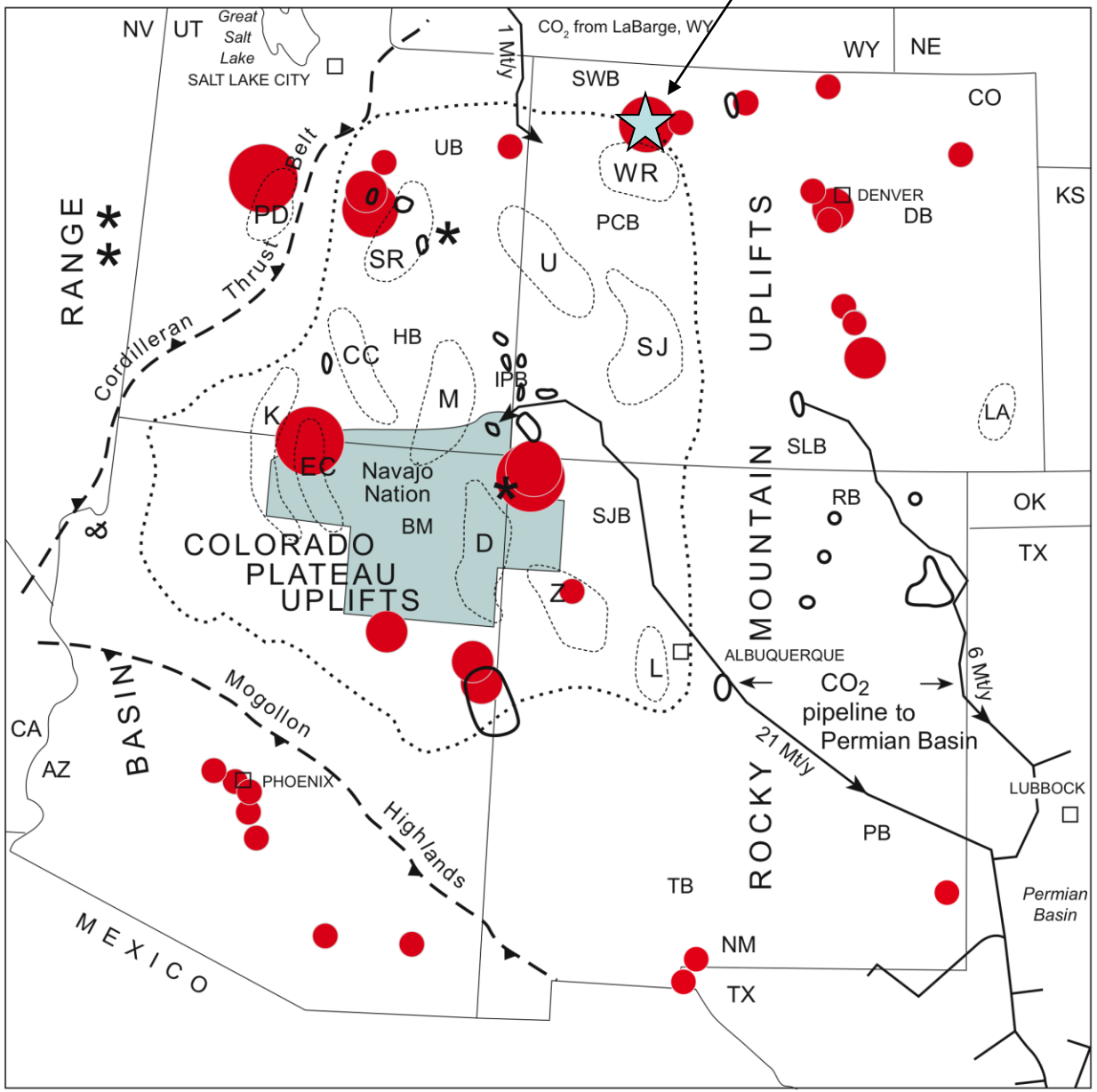
EXAMPLE: Regional Emissions

Point Sources :

~318 million tons CO_2 per year



Case Study Area



Expected Outcomes

Optimize Capacity Estimation: Number of Years for Specific Sources

From Atlas II:

Saline Formation CO_2 Storage Resource by State (million metric tons)		
State	**Low CO_2 Storage Resource**	**High CO_2 Storage Resource**
Arizona	199	752
Colorado	18,828	75,313
Kansas	8	9
Nebraska	87	348
New Mexico	33,054	132,215
Oklahoma	2	9
Texas	11,700	46,800
Utah	24,934	99,305
Wyoming	4,909	19,636

EXAMPLE: Regional Emissions

Point Sources :

~318 million tons CO_2 per year

$$\frac{700{,}000 \ million \ metric \ tons}{318 \ million \ metric \ tons/yr}$$

$$\approx 2{,}200 \ years$$

Maximum estimated SW saline capacity:
700,000 million metric tons

Expected Outcomes

EXAMPLE: Utah Emissions & Capacity

Sources : ~35 million metric tons CO_2 per year

Utah's CO_2 Sinks and Capacities:

Saline Formation CO_2 Storage Resource by State (million metric tons)		
State	**Low CO_2 Storage Resource**	**High CO_2 Storage Resource**
Arizona	199	752
Colorado	18,828	75,313
Kansas	8	9
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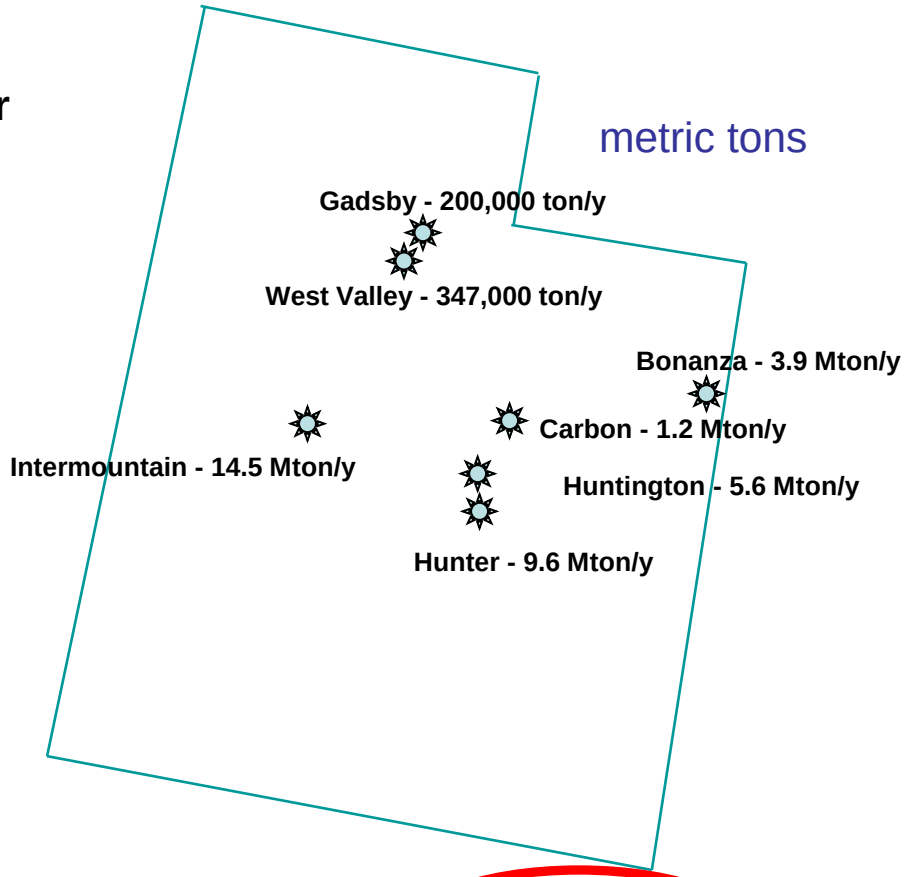
From Atlas II



$$\frac{99{,}305\ Mtons}{35\ Mtons/yr} \approx 2800\ years$$

Expected Outcomes: Improved MVA

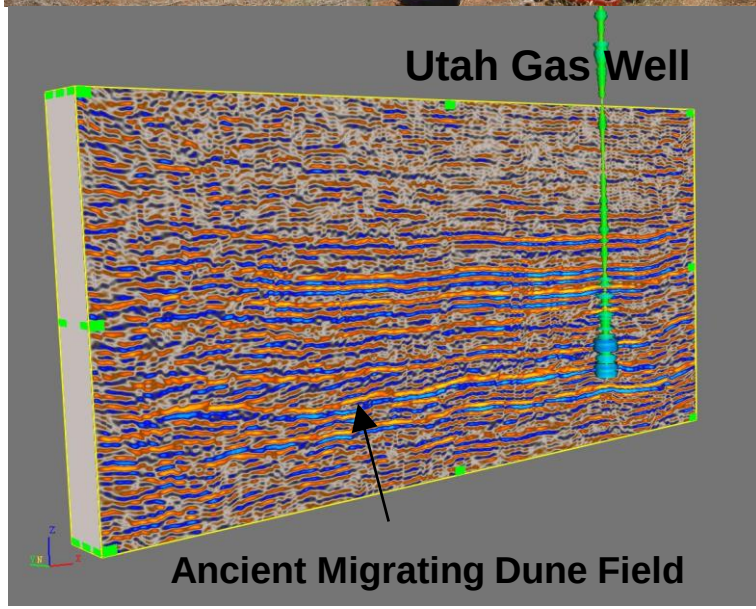
Better Characterization Provides More Effective Monitoring Design

<u>Monitoring for Detecting CO_2 in non-Targets:</u>

- Groundwater chemistry (non-target reservoirs)
- Surface CO_2 chamber flux
- Shallow CO_2 "piezometers" for sub-bio flux
- Remote sensing / LandSat Imaging
- Coupled process reservoir modeling

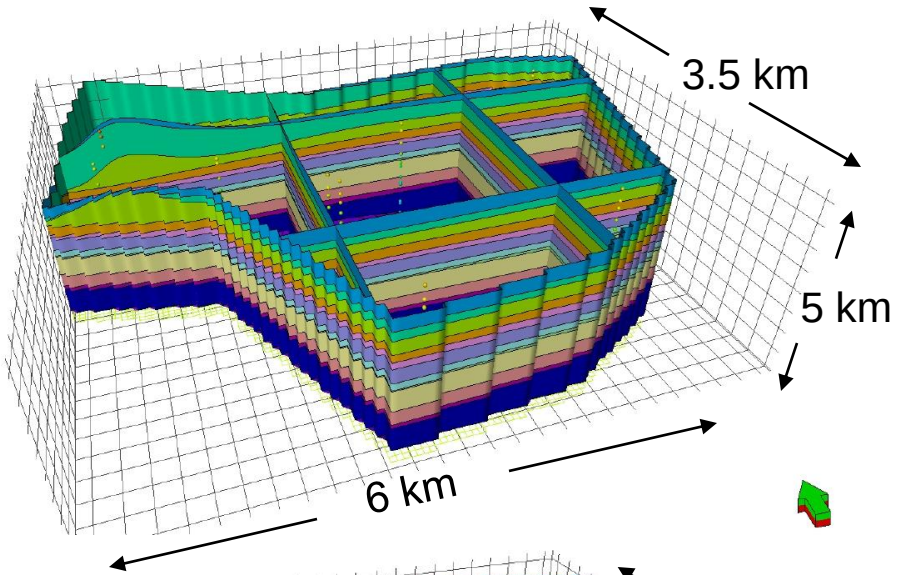
<u>Monitoring for Tracking CO_2 Migration and Fate</u>

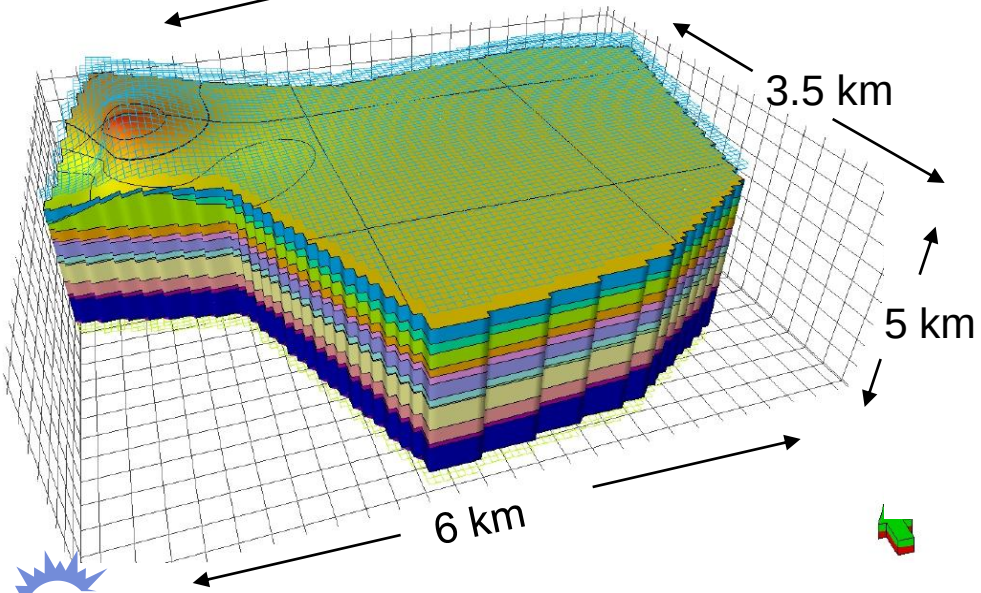
- 2-D and/or 3-D seismic reflection
- Vertical seismic profiles (VSP)
- Crosswell seismic imaging
- Passive seismic monitoring/imaging
- Groundwater chemistry (target reservoir)
- In situ pressure, temperature measurements
- In situ bicarbonate detection
- Coupled process reservoir modeling
- Microgravity surveys



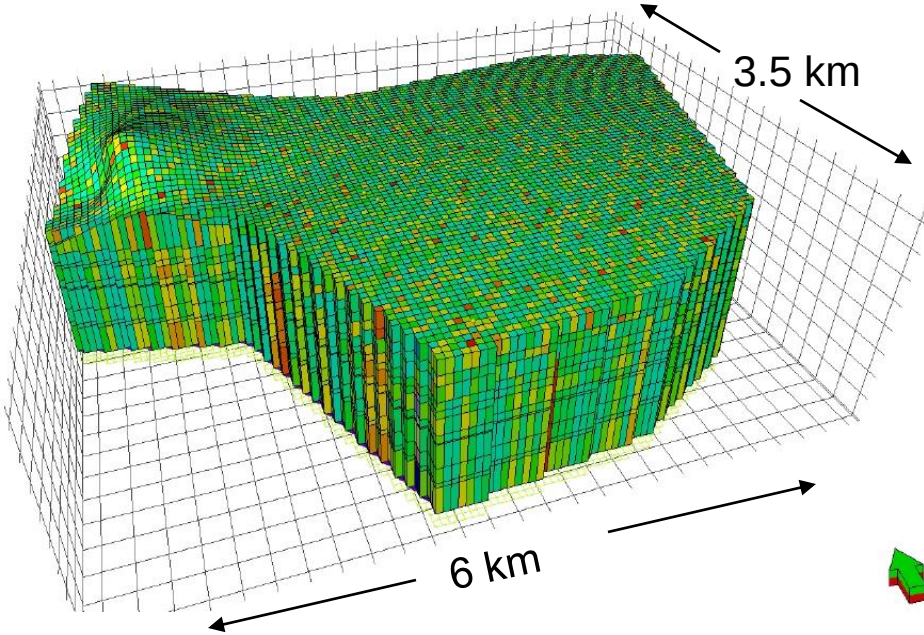
Focus monitoring on: resolved risk FEPS or unresolved areas

Expected Outcomes: Improved Models

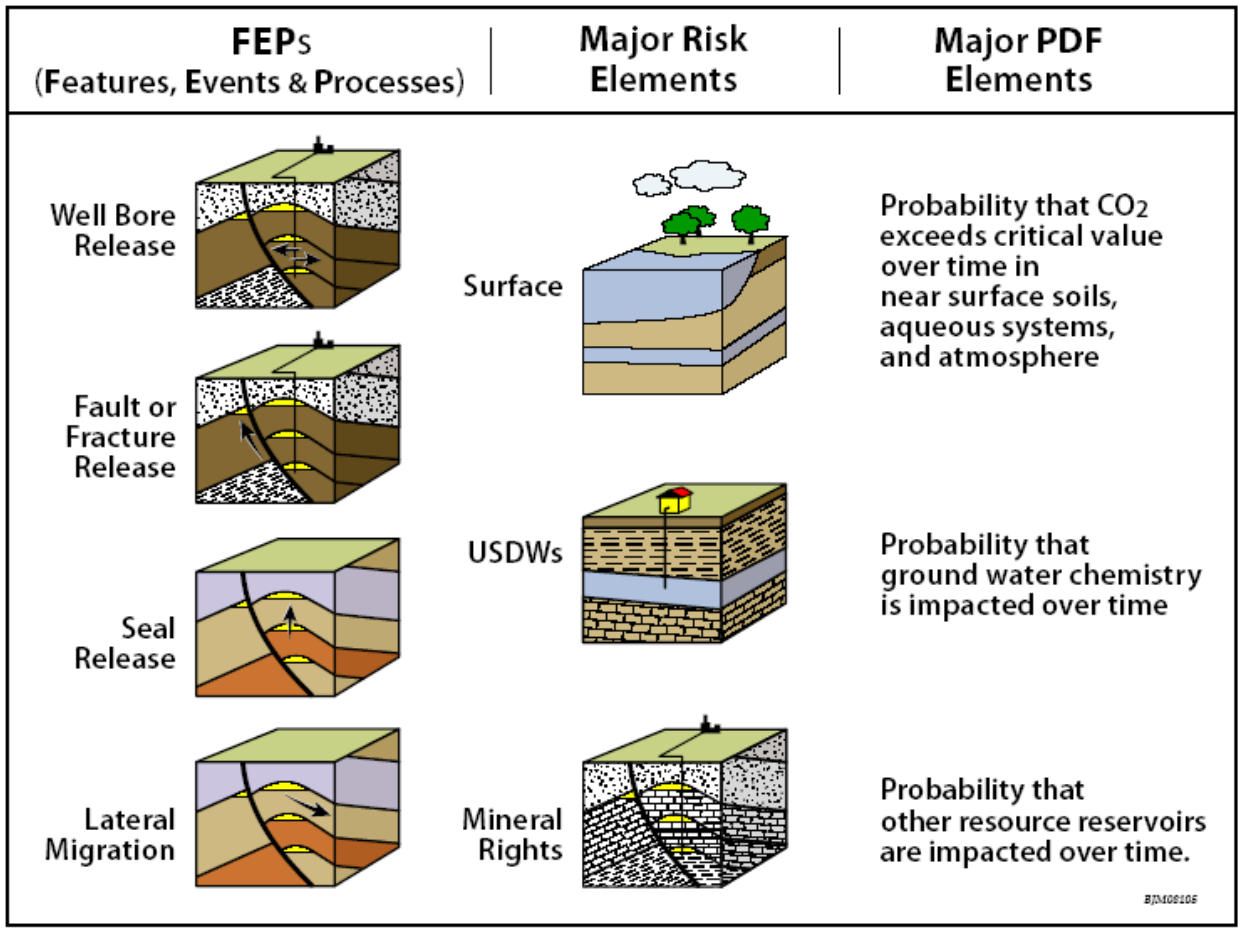




- spatial and temporal resolution of models **must** match resolution of monitoring technologies - better characterization will help dramatically!



Expected Outcomes: Reduced Uncertainty



Modified from Guthrie et al.

- Improved PDF protocols (risk quantification)

Top Goal and Deliverable

Top goal:
identify the most effective criteria for ranking potential storage sites throughout the region.

Top Deliverable:
Final Site Characterization Plan and Protocols, Including Site-Selection Criteria

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Project Plan

I. Local Site Characterization

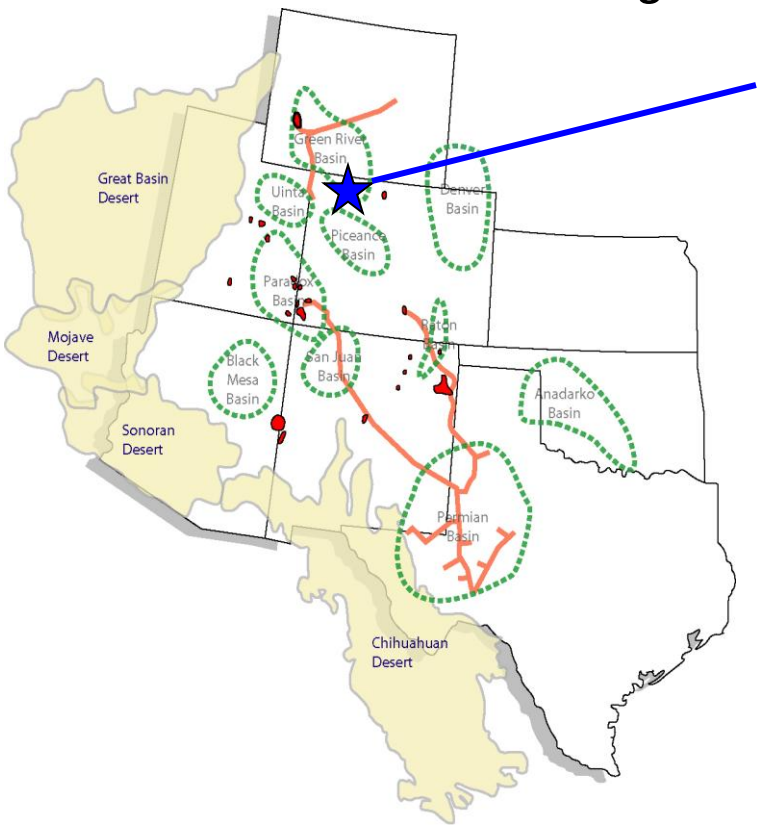
II. Extend Local Results to State-Scale

III. Finalize Regional Protocol

Project Plan

I. Local Site Characterization

Complete high-resolution characterization of "archetype" sites in each state of the region.



(1) Colorado - Laramide Structure at Craig

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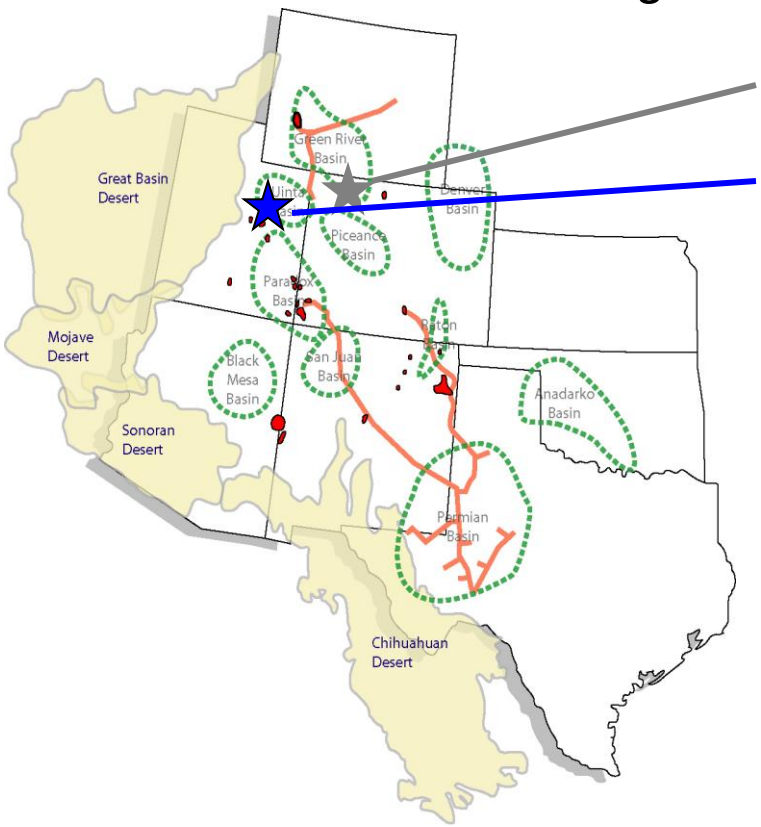

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(2) Utah - Uinta Basin Area

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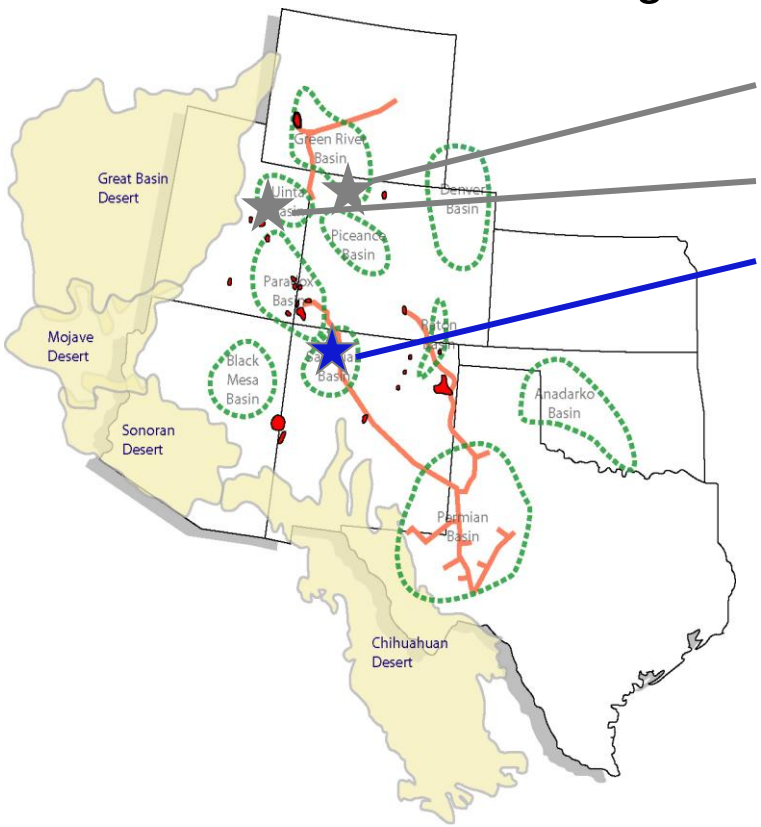

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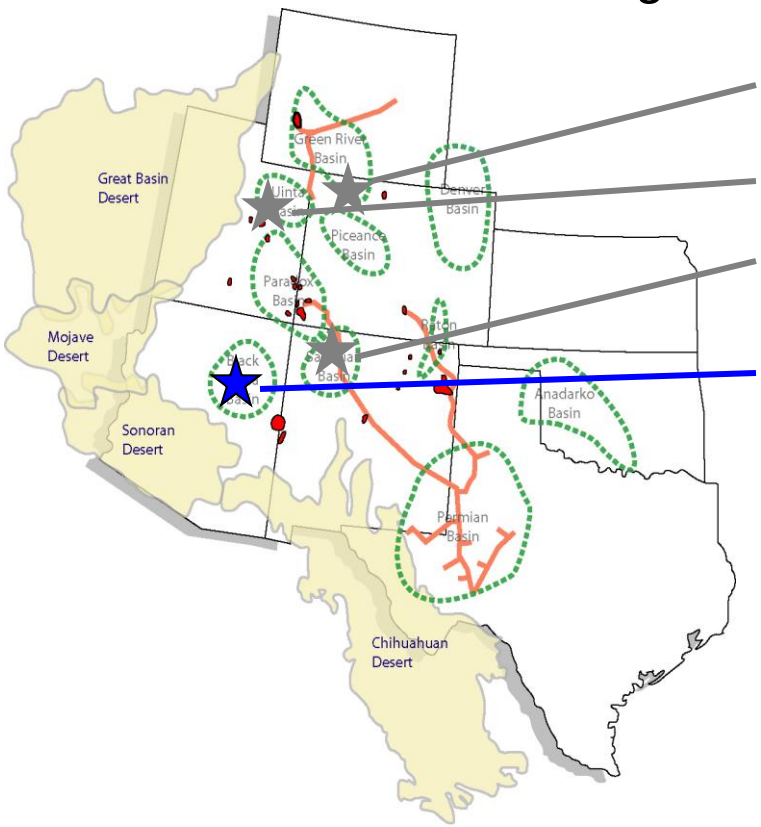

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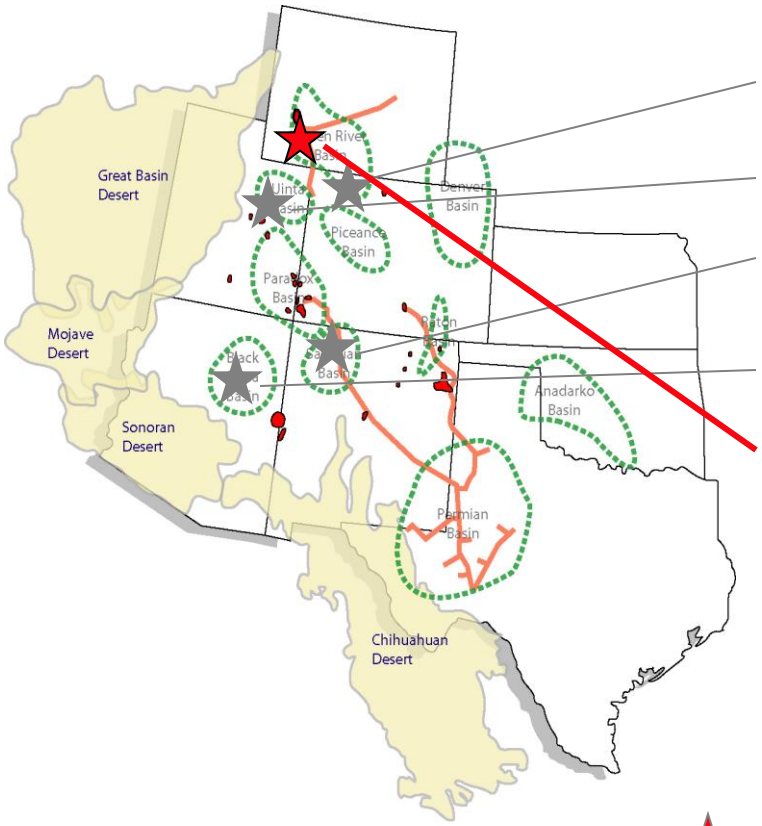
(4) Arizona - Black Mesa Basin

Project Plan

I. Local Site Characterization

Complete high-resolution characterization of "archetype" sites in each state: Adjacent ARRA Characterization Projects



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★ = Adjacent ARRA Char. Projects

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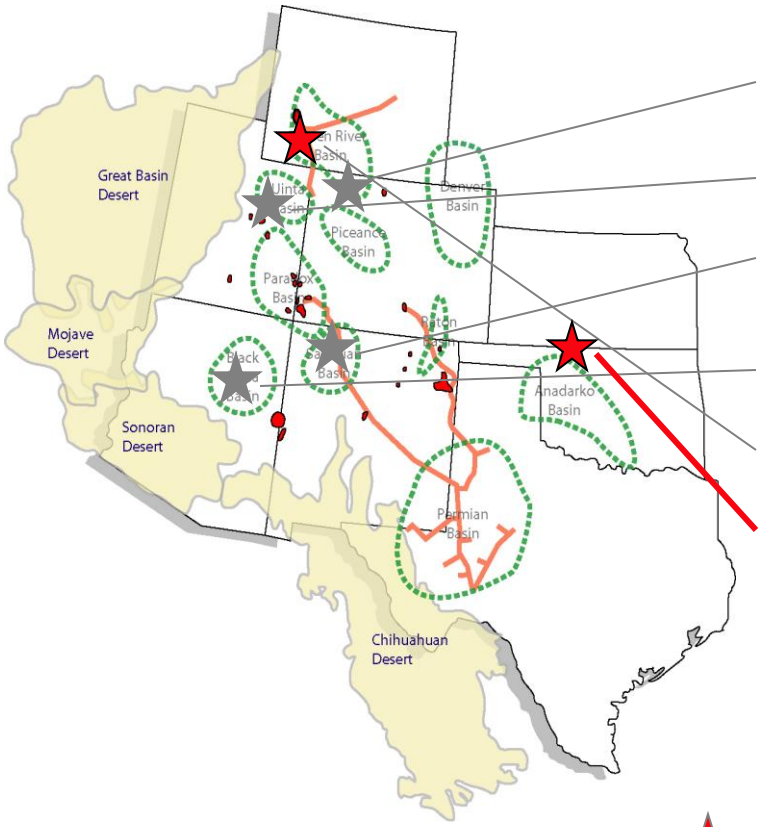

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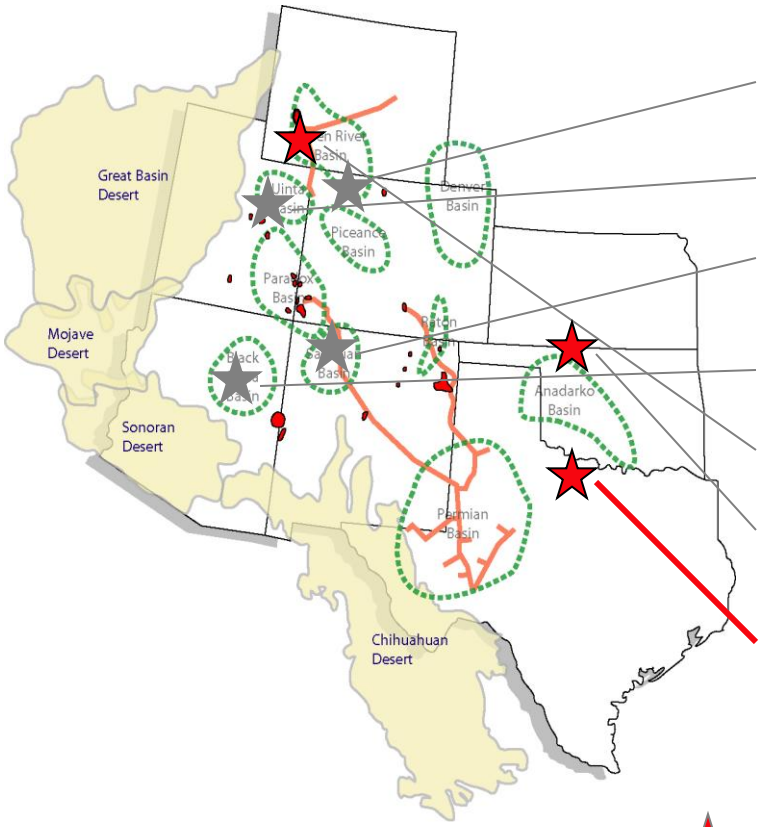

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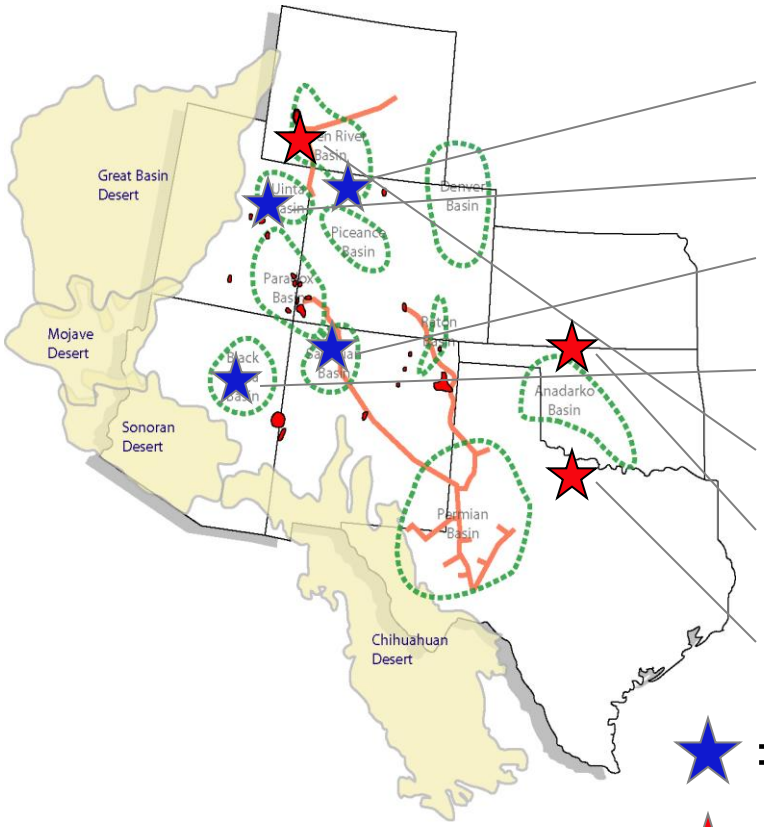

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★ = RMCCS Local Sites

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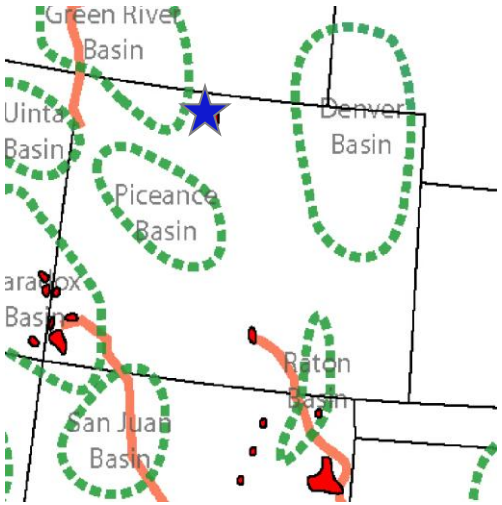
Project Plan

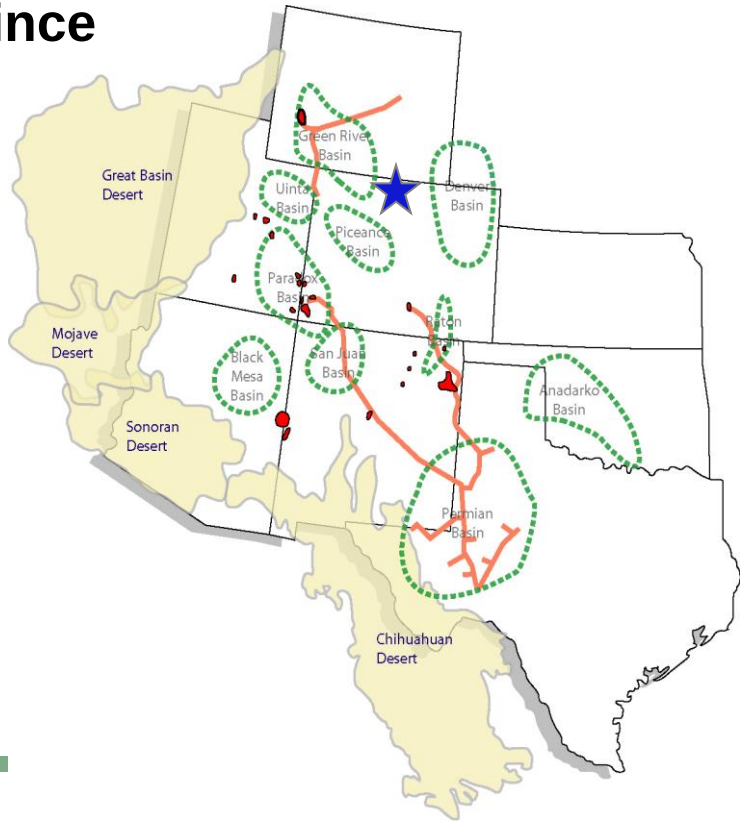
II. Extend Local Results to State-Scale

For each archetype site in each state, evaluate features common to (and in contrast to):

- **Rest of basin or structure**
- **Adjacent basins and structures**
- **Rest of state**
- **Rest of physiographic province**

For example: Colorado





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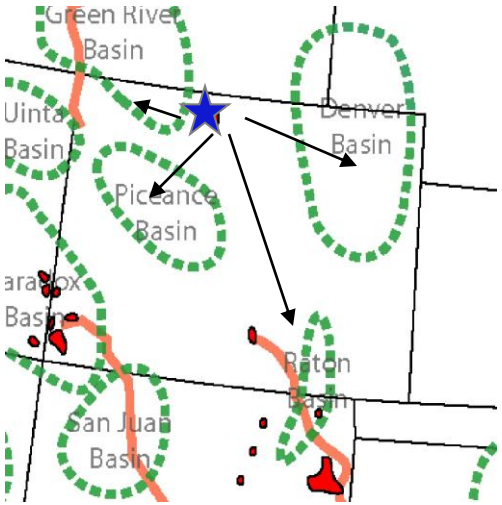

Must evaluate features at Craig that are common to other basins and structures in the state, as well as those that are different. What geologic aspects of the most promising formations promote effective storage and monitoring?

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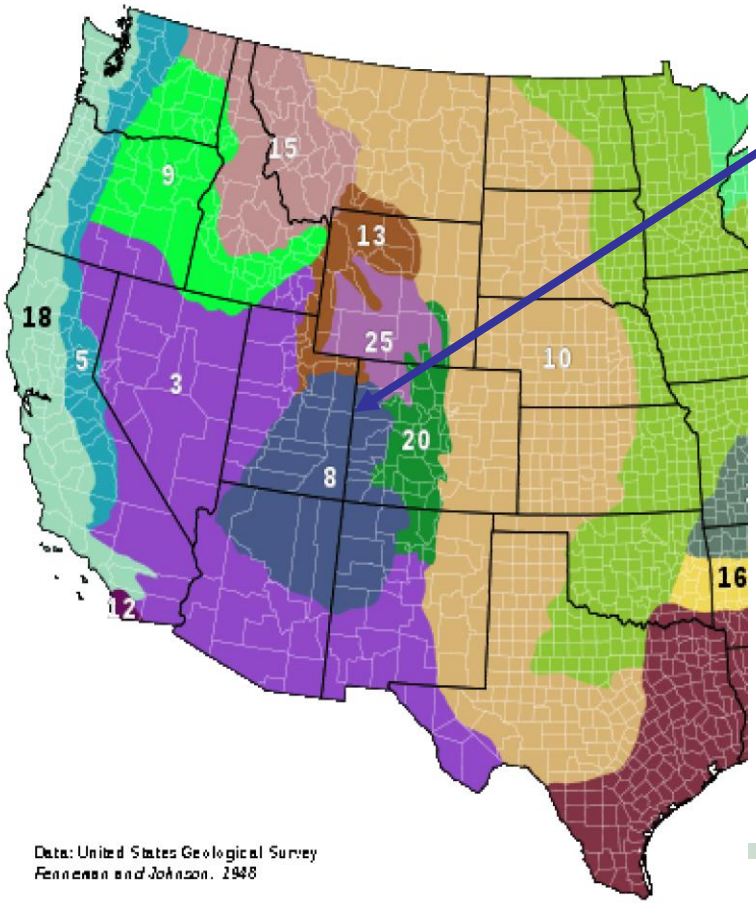

Colorado Plateau

Project Plan

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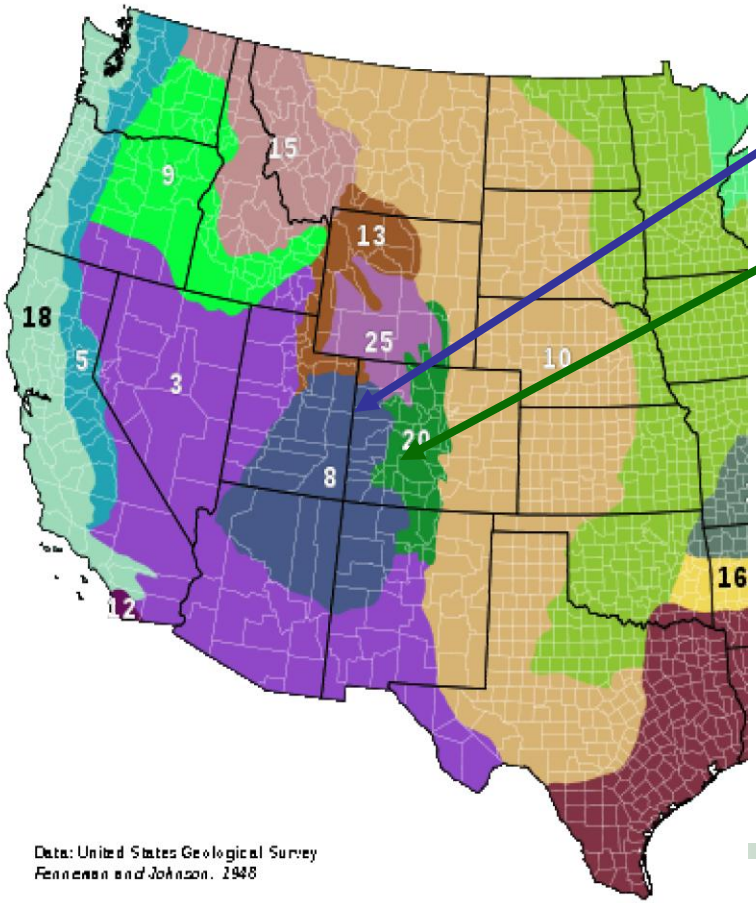

Colorado Plateau

Southern Rocky Mountains

Project Plan

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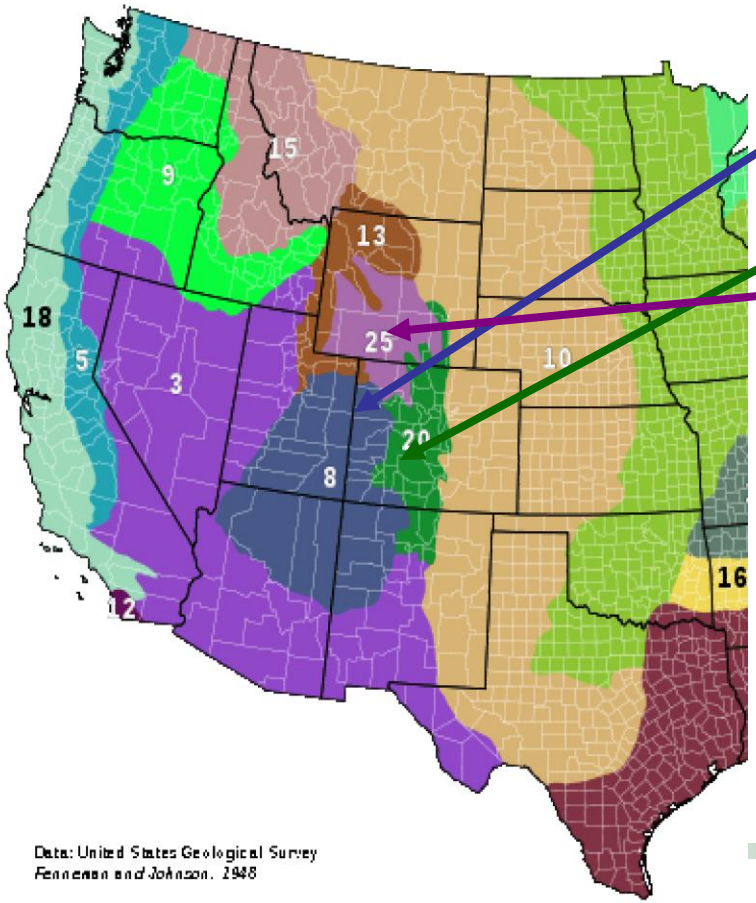
- **Rest of physiographic province**



Colorado Plateau

Southern Rocky Mountains

Middle Rocky Mountains

Project Plan

II. Extend Local Results to State-Scale

For each archetype site in each state, evaluate features common to (and in contrast to):

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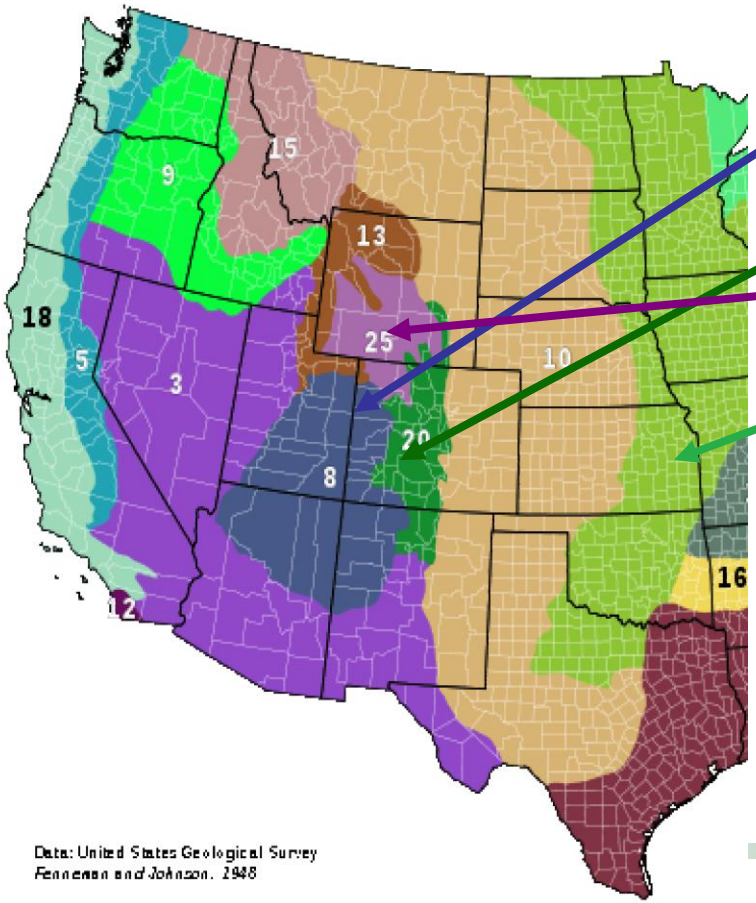

Colorado Plateau

Southern Rocky Mountains

Middle Rocky Mountains

Central Lowland

Project Plan

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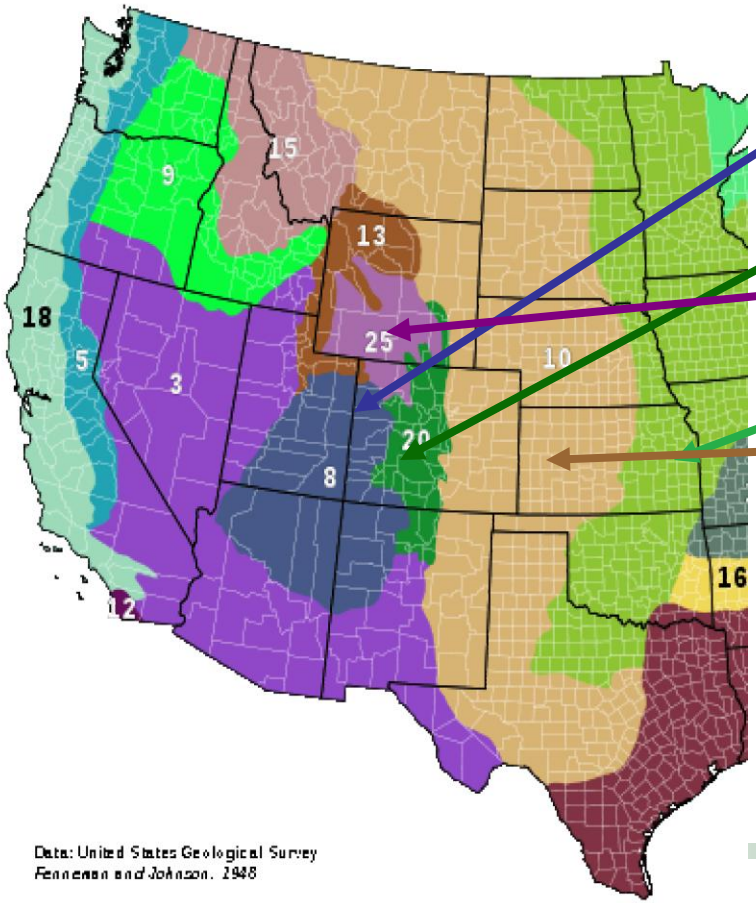

Colorado Plateau

Southern Rocky Mountains

Middle Rocky Mountains

Central Lowland

Great Plains

Data: United States Geological Survey
Fenneman and Johnson, 1946

Project Plan

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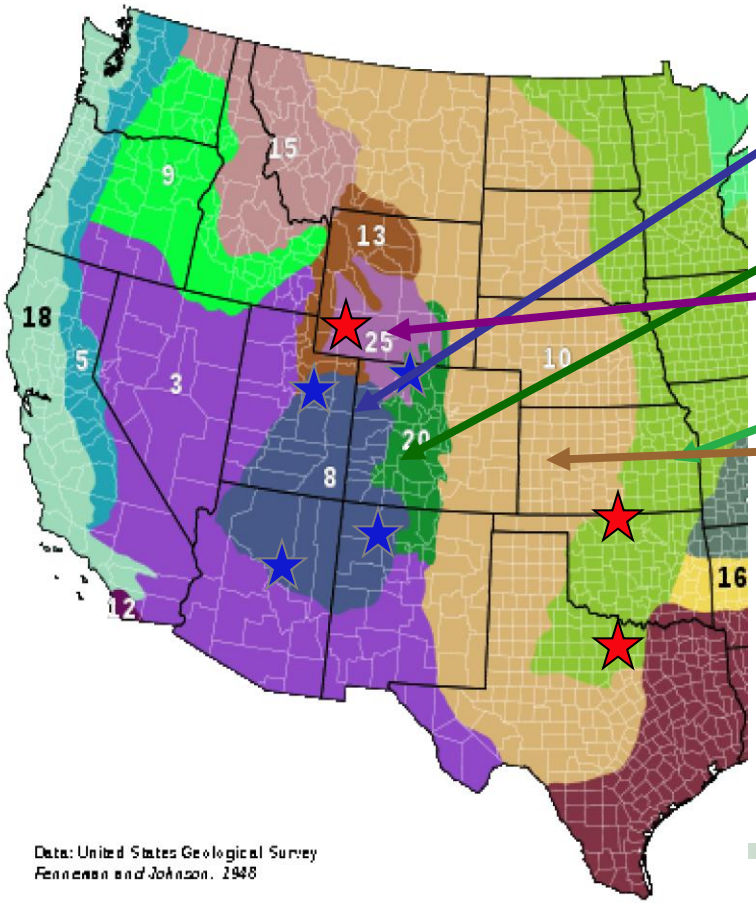


Colorado Plateau

Southern Rocky Mountains

Middle Rocky Mountains

Central Lowland

Great Plains

The “local” sites/areas lie within five different physiographic provinces!

Project Plan

III. Finalize Regional Protocol

Based on the common and contrasting features within the different

- local sites
- states
- physiographic provinces

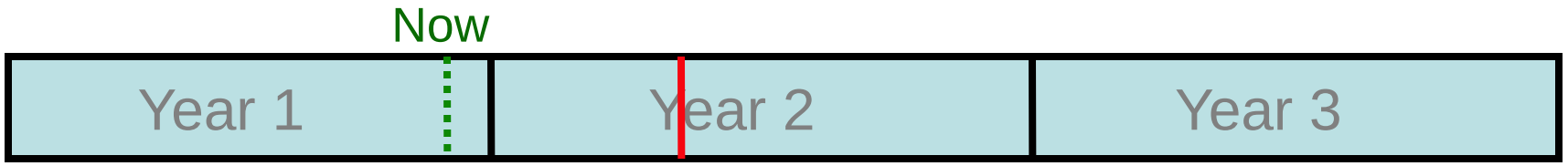
develop a **comprehensive "blueprint" protocol** for site and formation characterization that fits all parts (states) of the region -- this is the most challenging aspect of the project!

Project Plan: Timeline

I. Local Site Characterization

II. Extend Local Results to State-Scale

III. Finalize Regional Protocol



Goal 1: local site characterization complete

Project Plan: Timeline

I. Local Site Characterization

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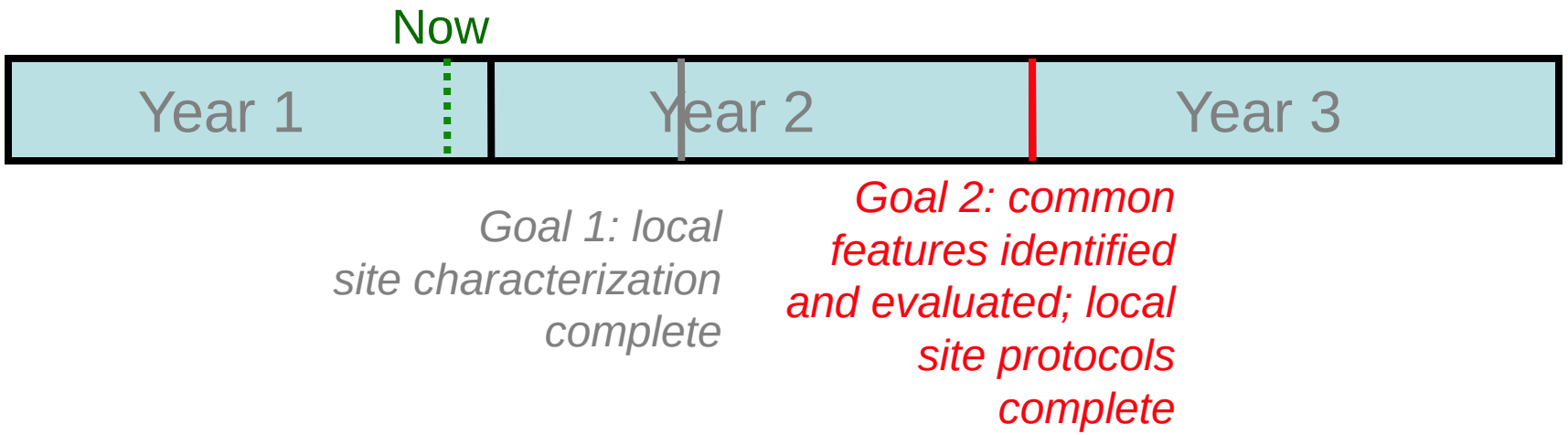

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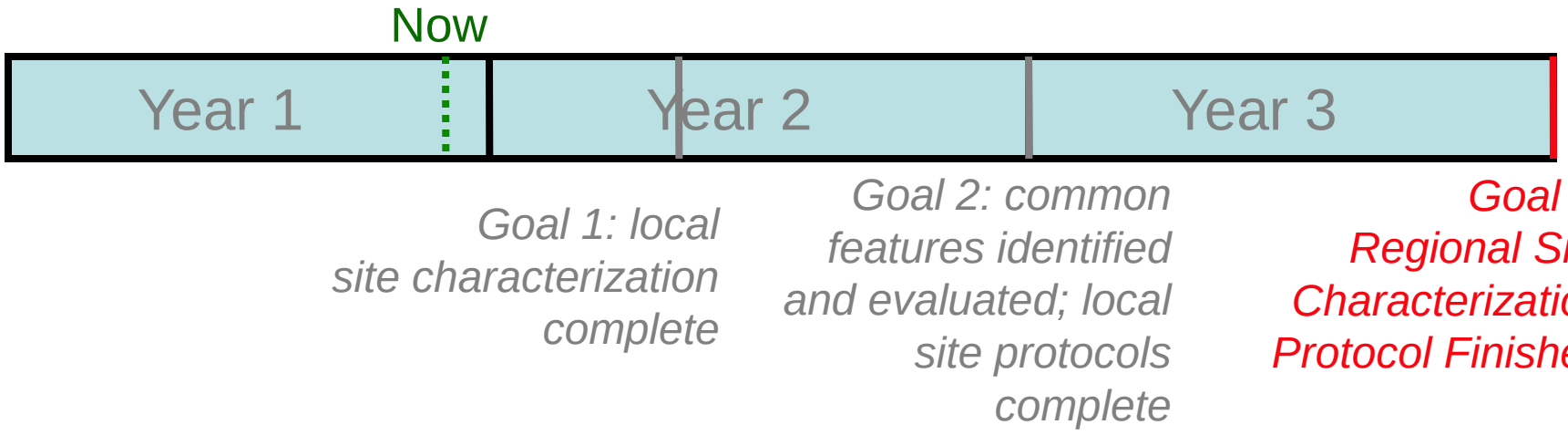

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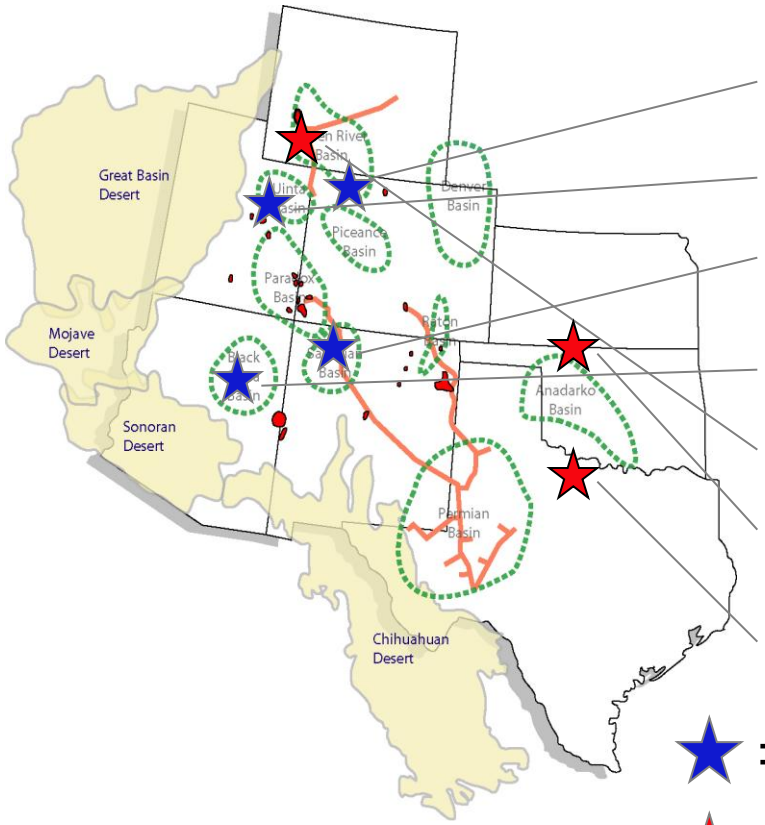
Progress to Date



(1) Colorado - Laramide Structure at Craig

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★ = RMCCS Local Sites

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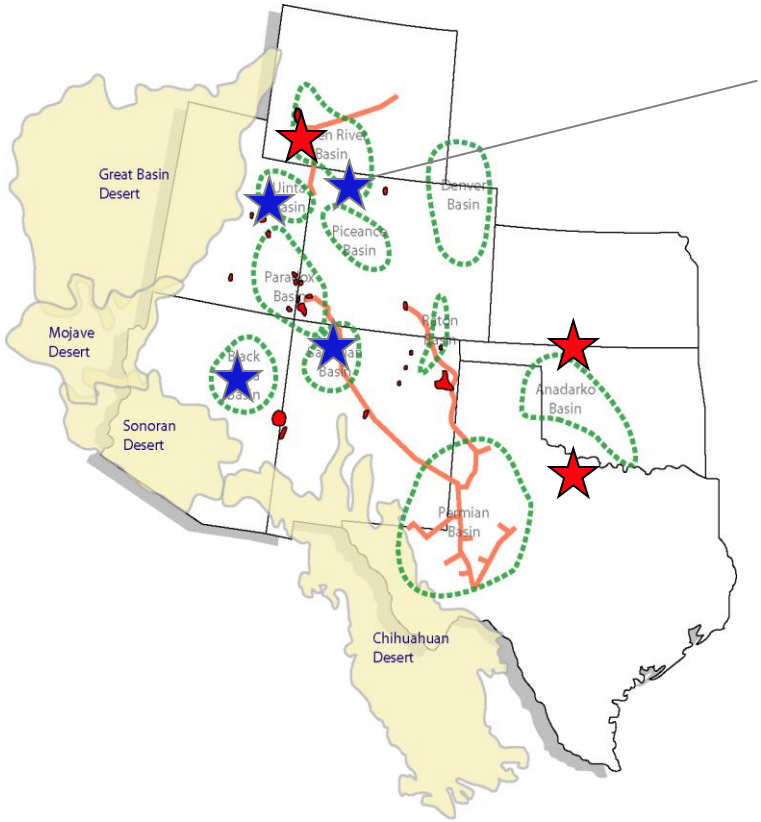
Progress to Date



(1) Colorado - Laramide Structure at Craig

Progress to Date: Craig, Colorado Site

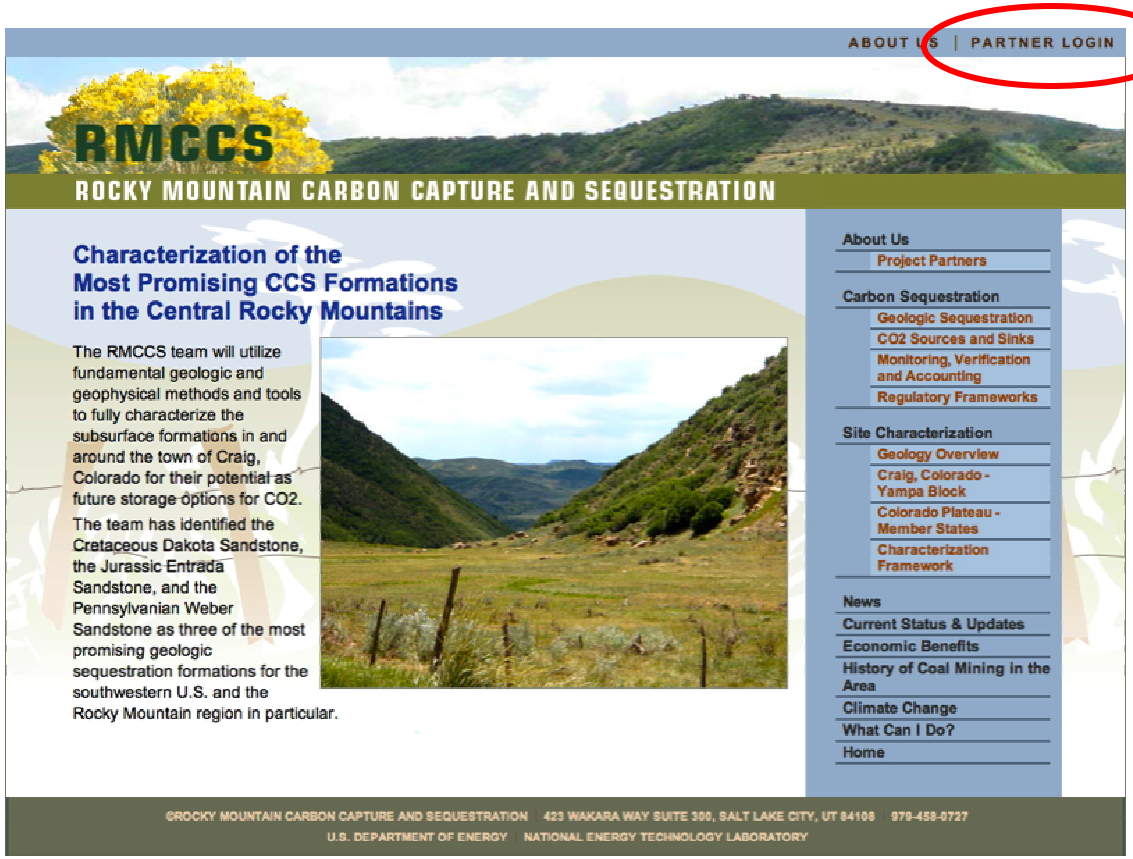
Progress so far:

- Database in place and evolving
- Existing seismic lines purchased
- Processing & interpreting seismic underway
- Mapping of structure underway
- New VSP lines being designed and planned
- Location for drill hole picked
- Permitting of well to begin ASAP

Progress to Date: Craig, Colorado Site

Progress so far:

- Database in place and evolving



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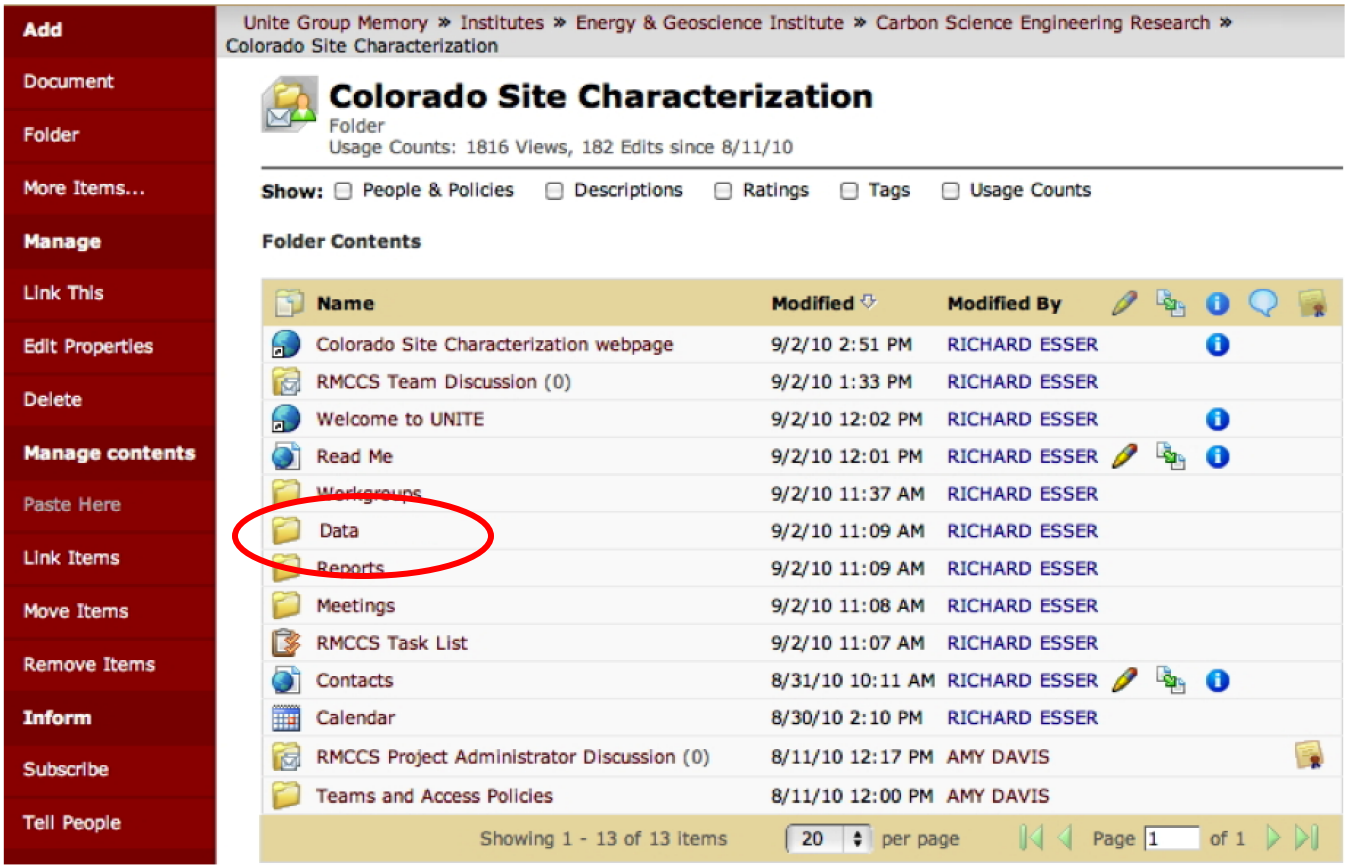

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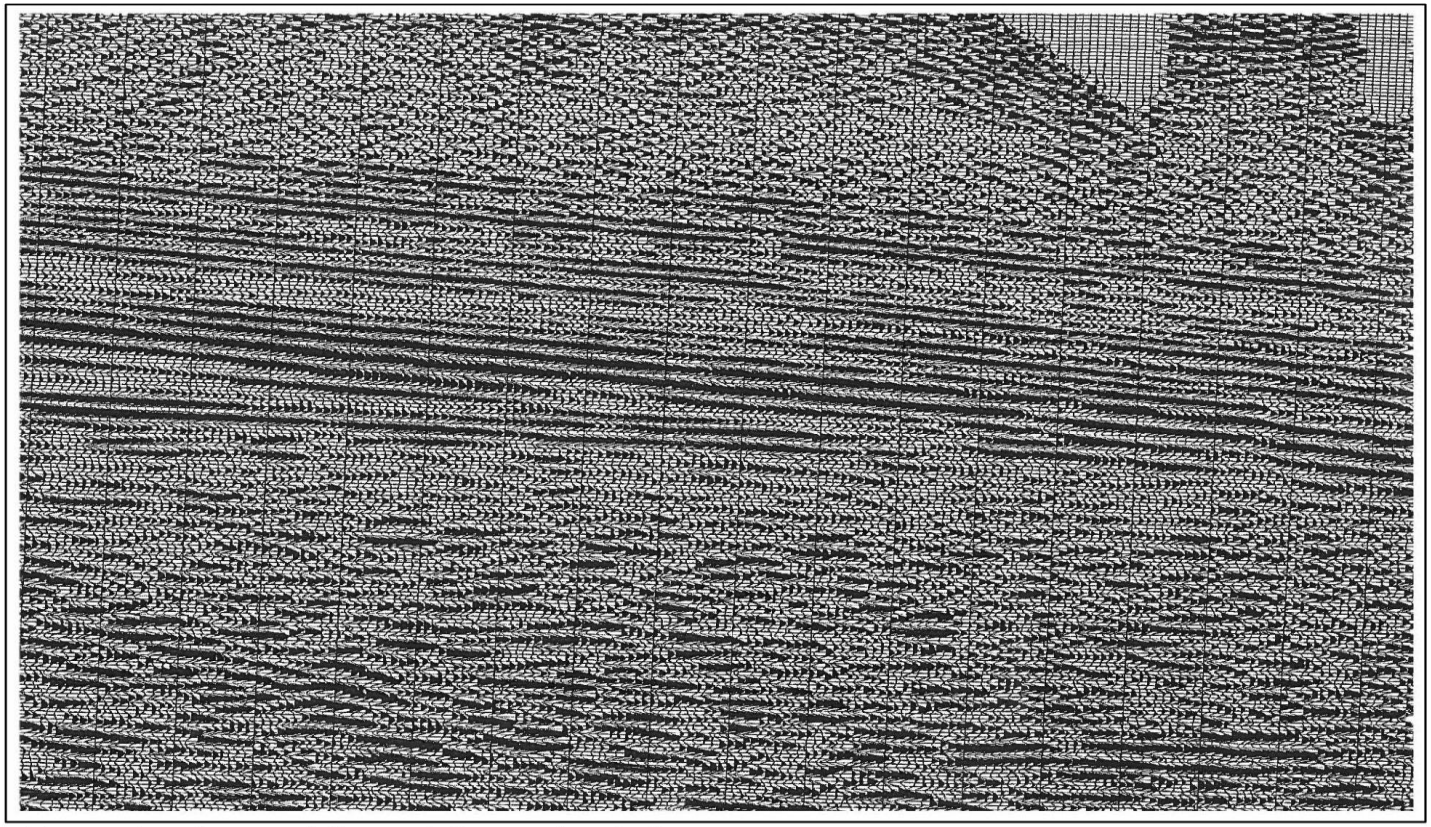
- Existing seismic lines purchased
- Processing & interpreting seismic underway



Example of one of the existing seismic lines

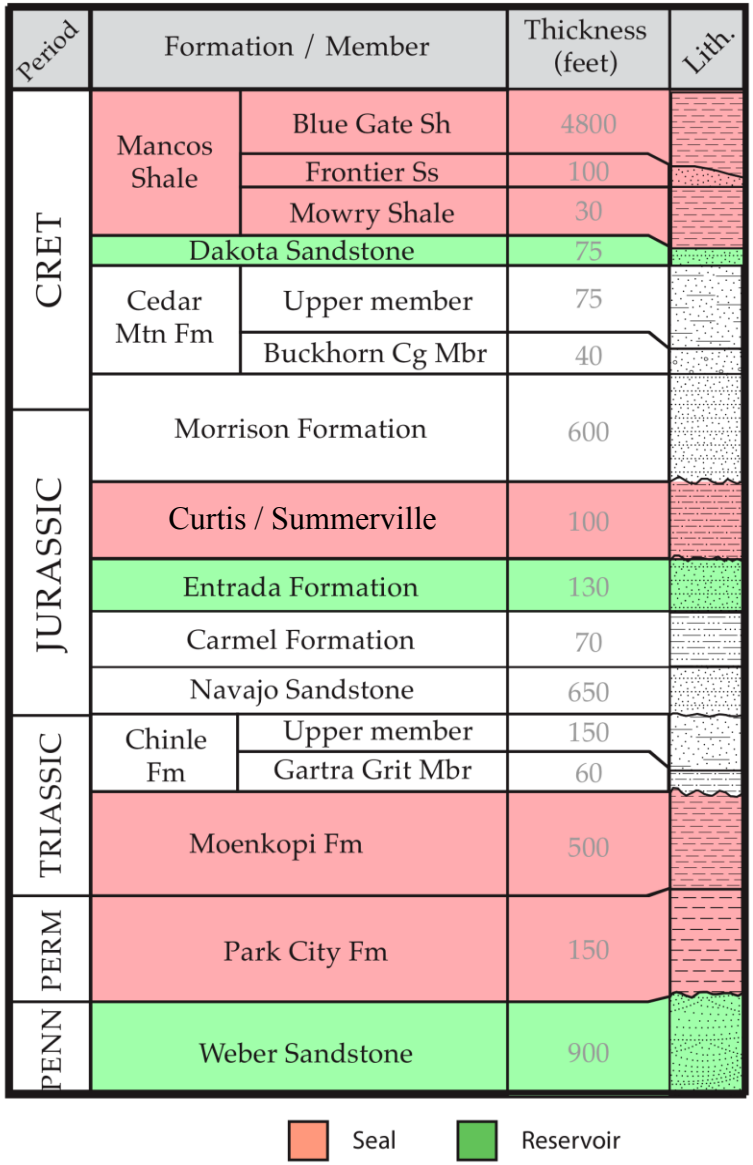
Progress to Date: Craig, Colorado Site

Progress so far:

- Database in place and evolving
- Existing seismic lines purchased
- Processing & interpreting seismic underway
- Mapping of structure underway

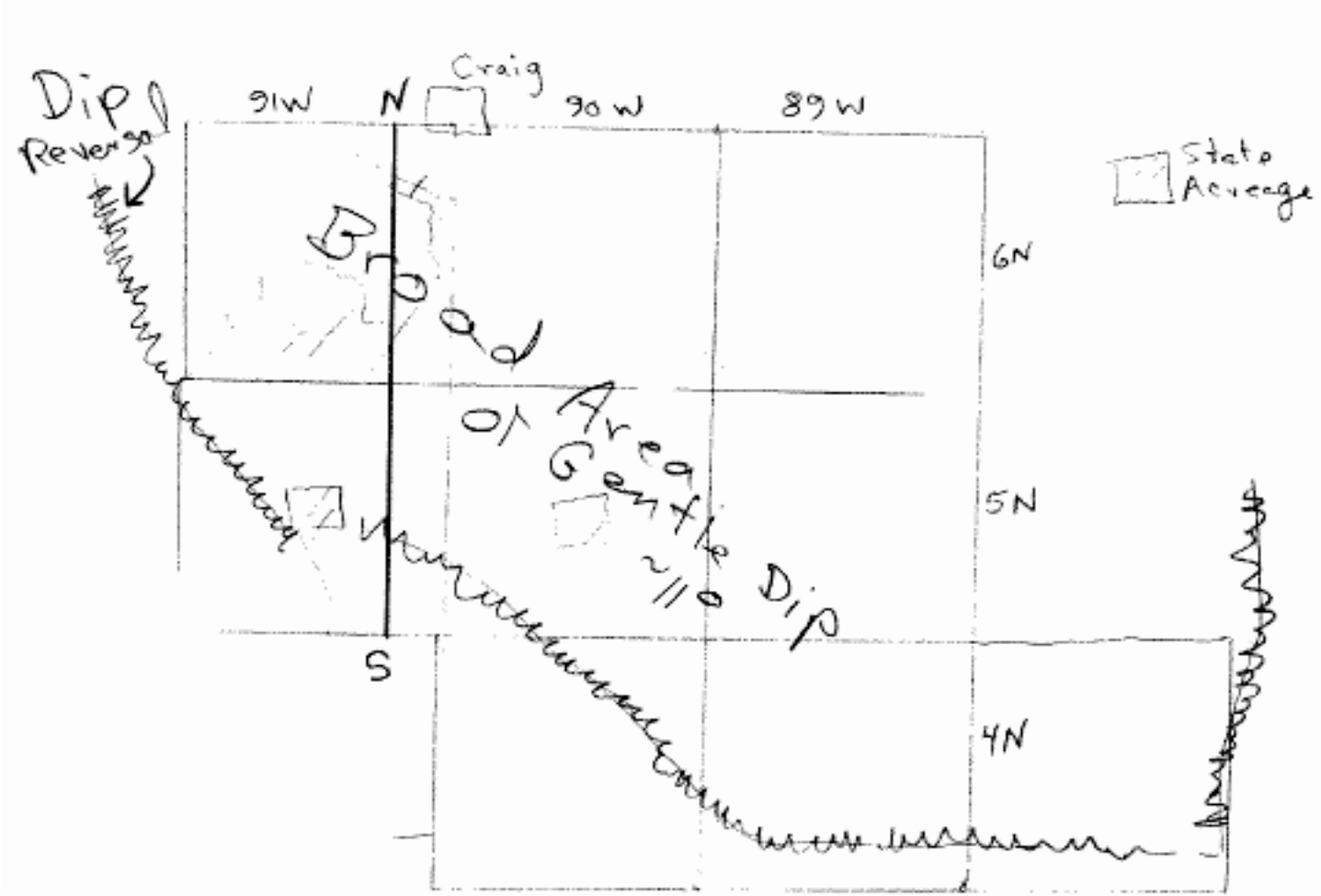
Progress to Date: Craig, Colorado Site

Mapping of structure underway



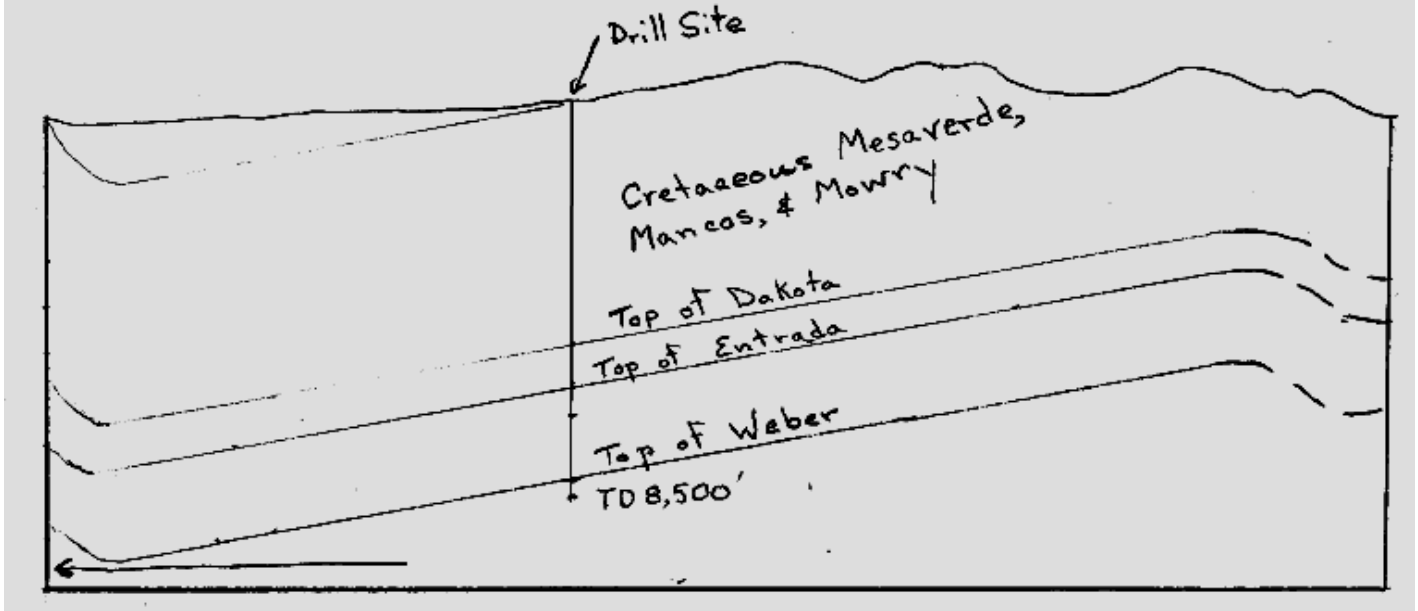
Progress to Date: Craig, Colorado Site

We developed simple conceptual models including 3-D



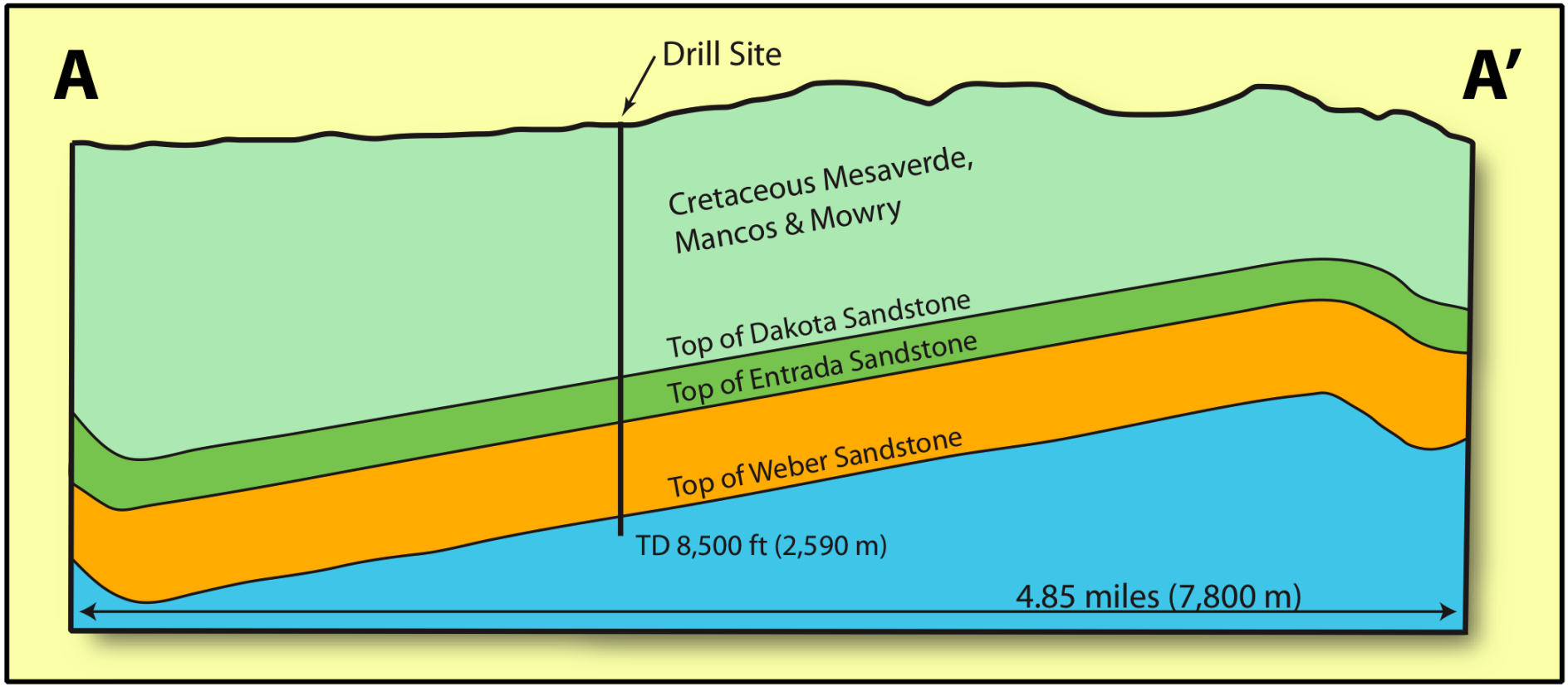
Progress to Date: Craig, Colorado Site

We developed simple conceptual models including 3-D and 2-D structural geology for initial model gridding and analysis



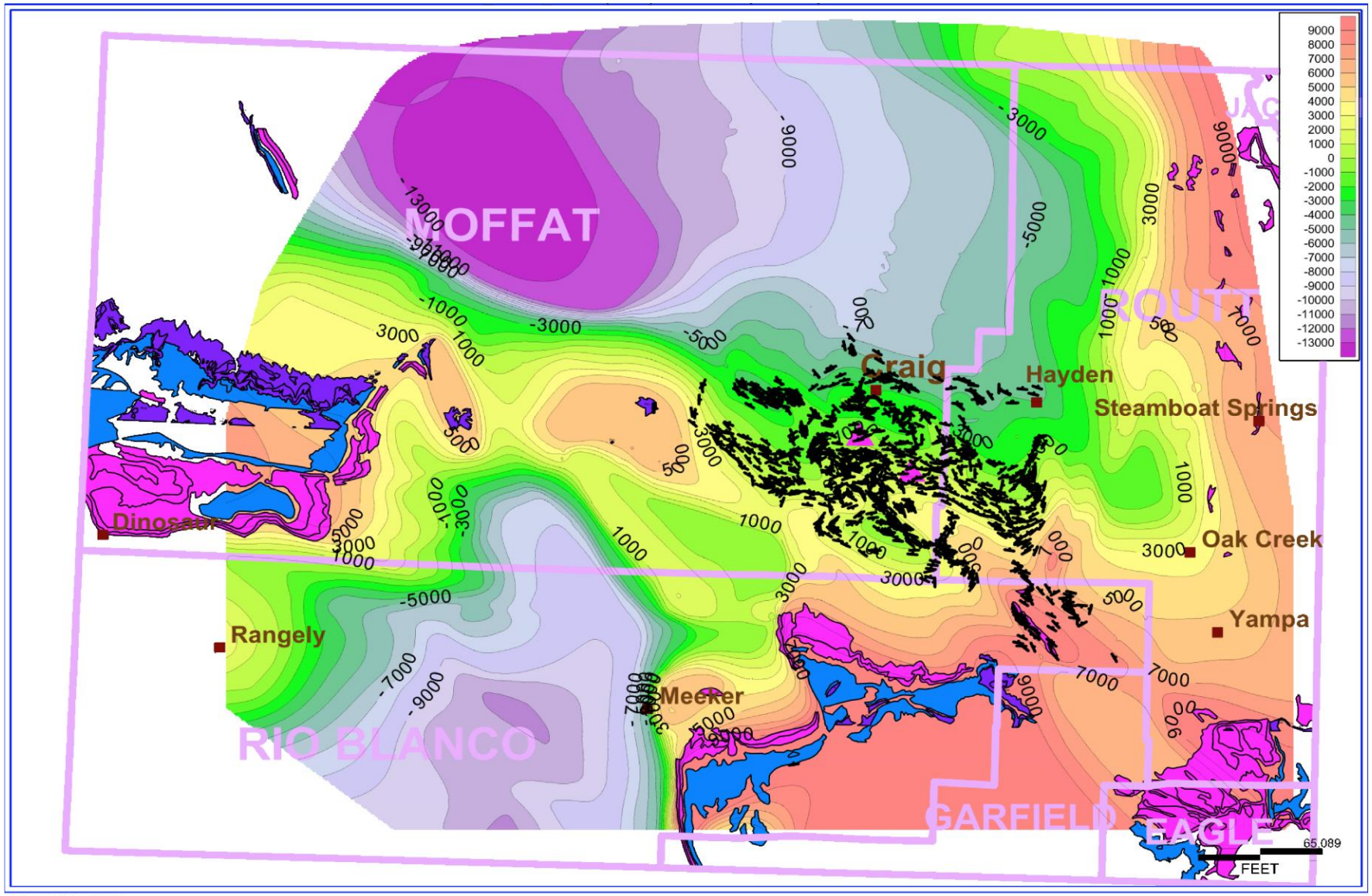
Progress to Date: Craig, Colorado Site

Mapping of structure underway



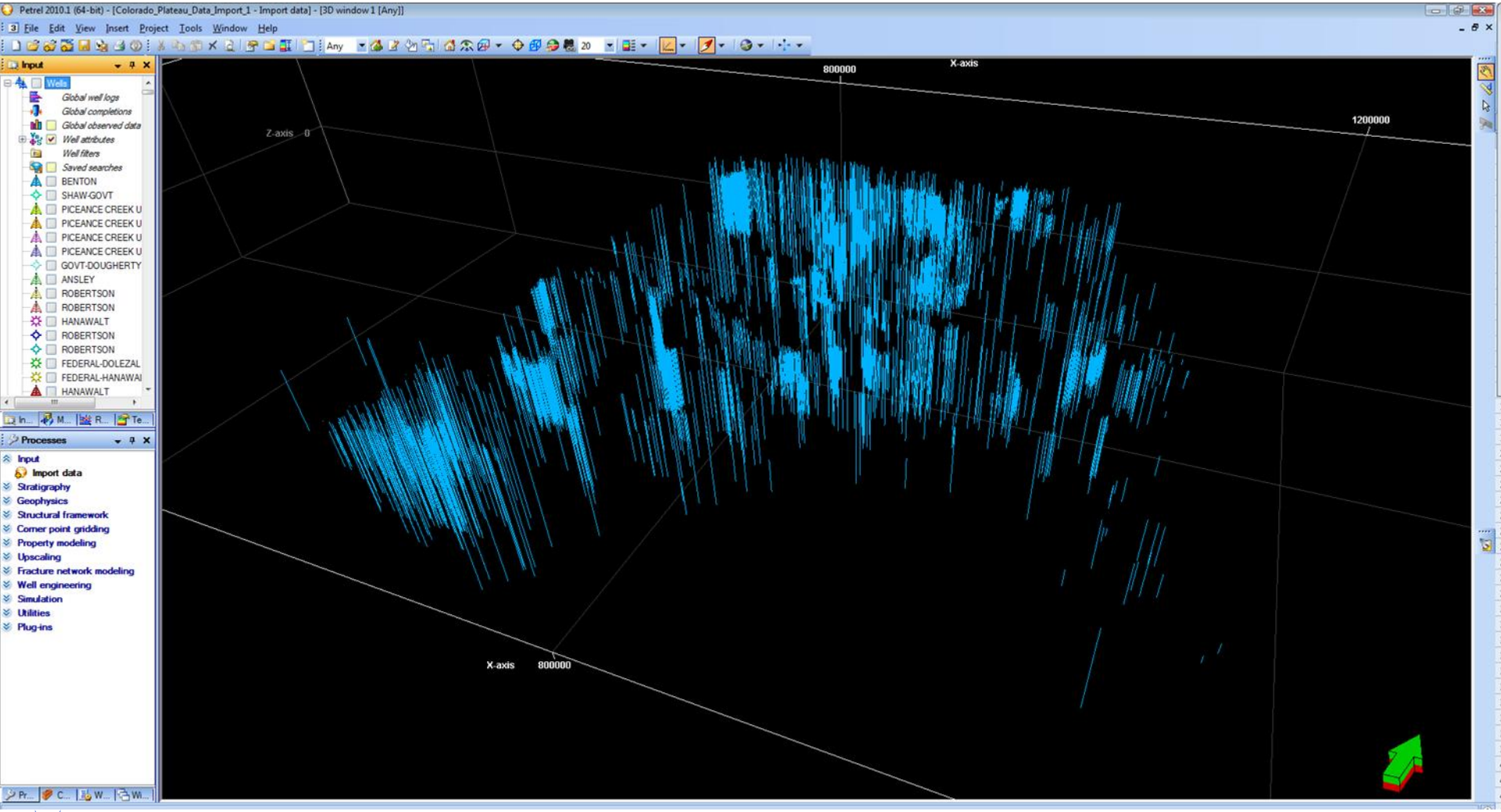
Progress to Date: Craig, Colorado Site

Detailed structure-contour map of Dakota:



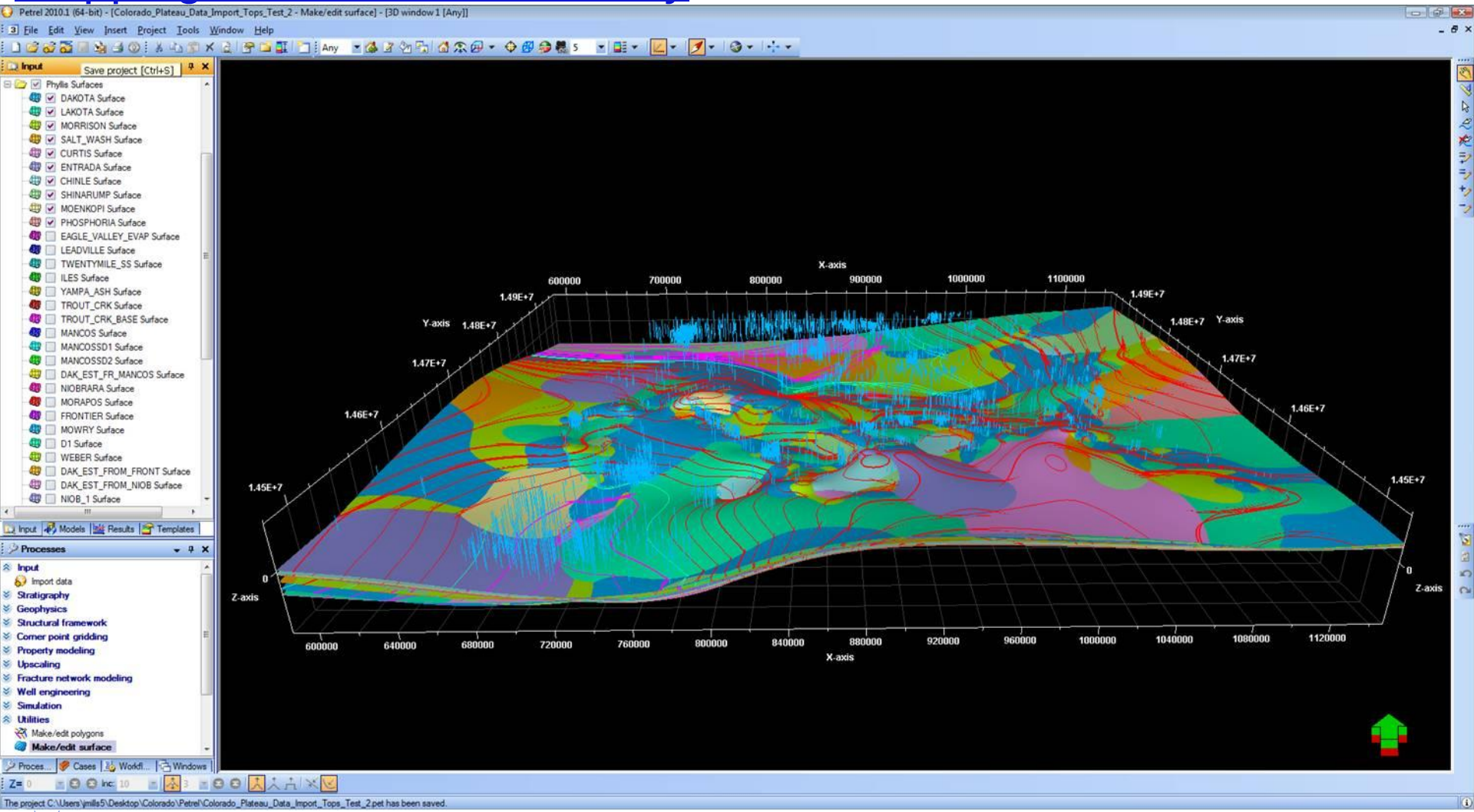
Progress to Date: Craig, Colorado Site

Mapping of structure underway



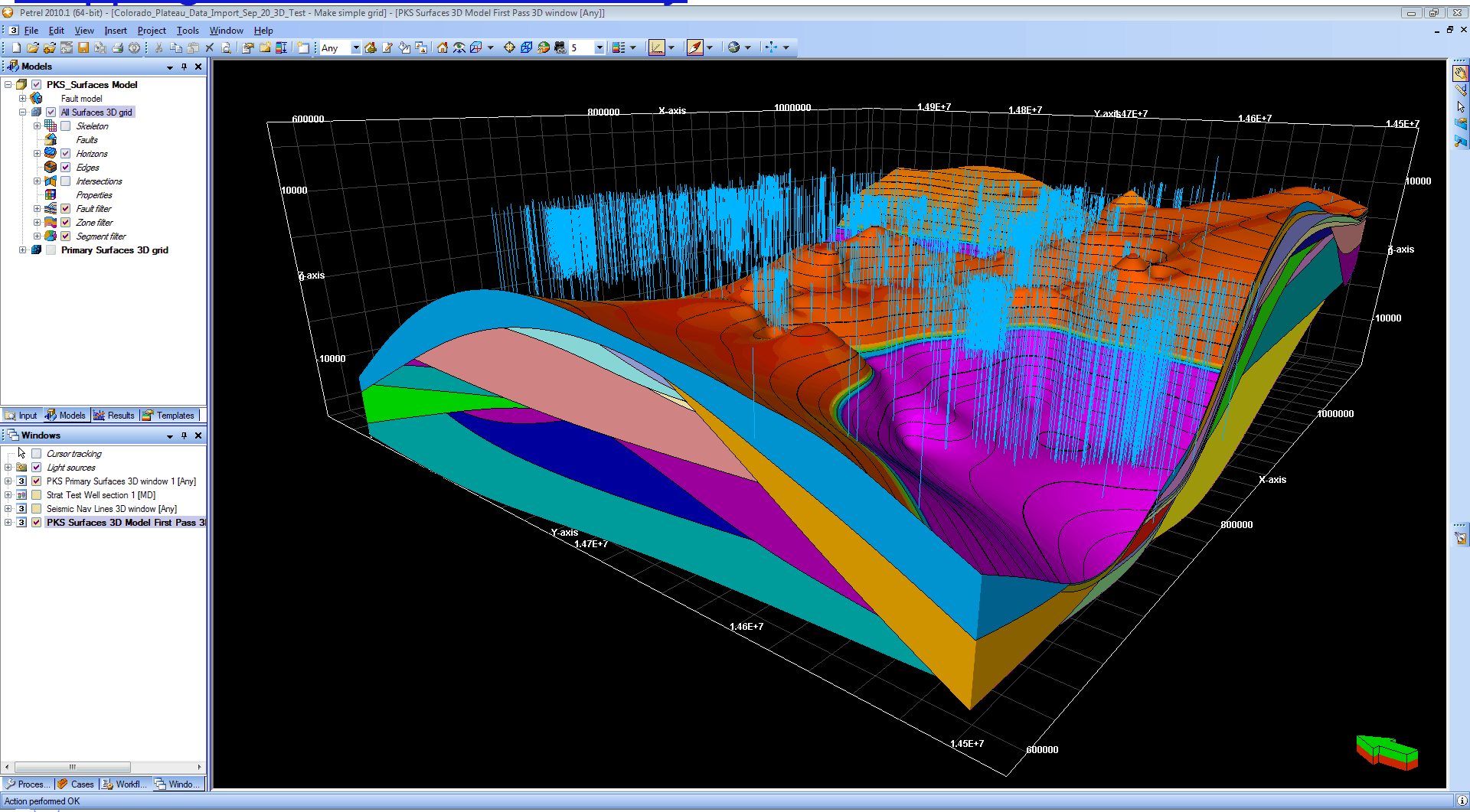
Progress to Date: Craig, Colorado Site

Mapping of structure underway



Progress to Date: Craig, Colorado Site

Mapping of structure underway



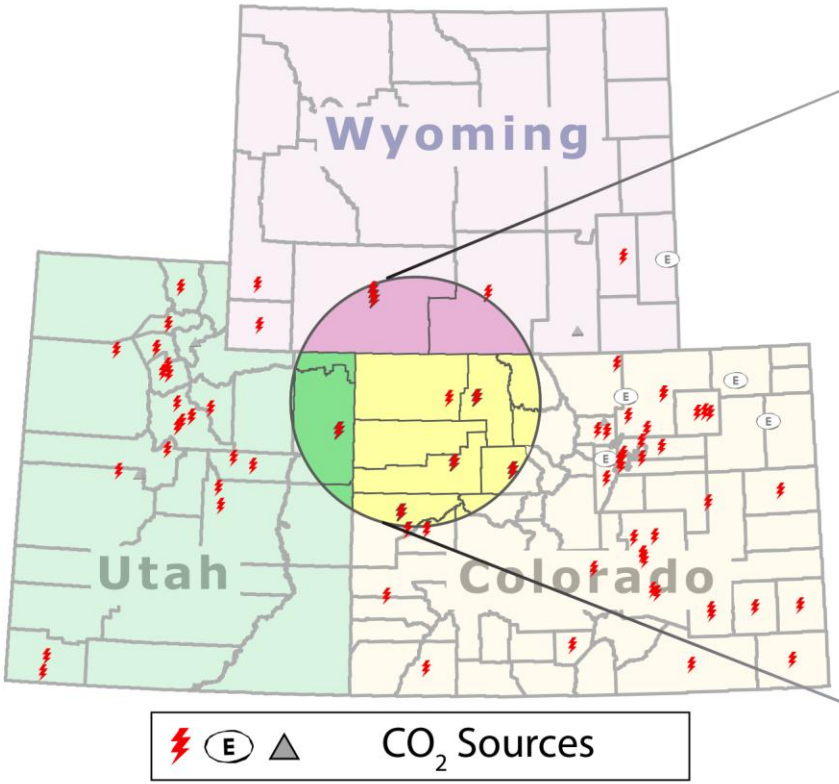
Progress to Date: Craig, Colorado Site

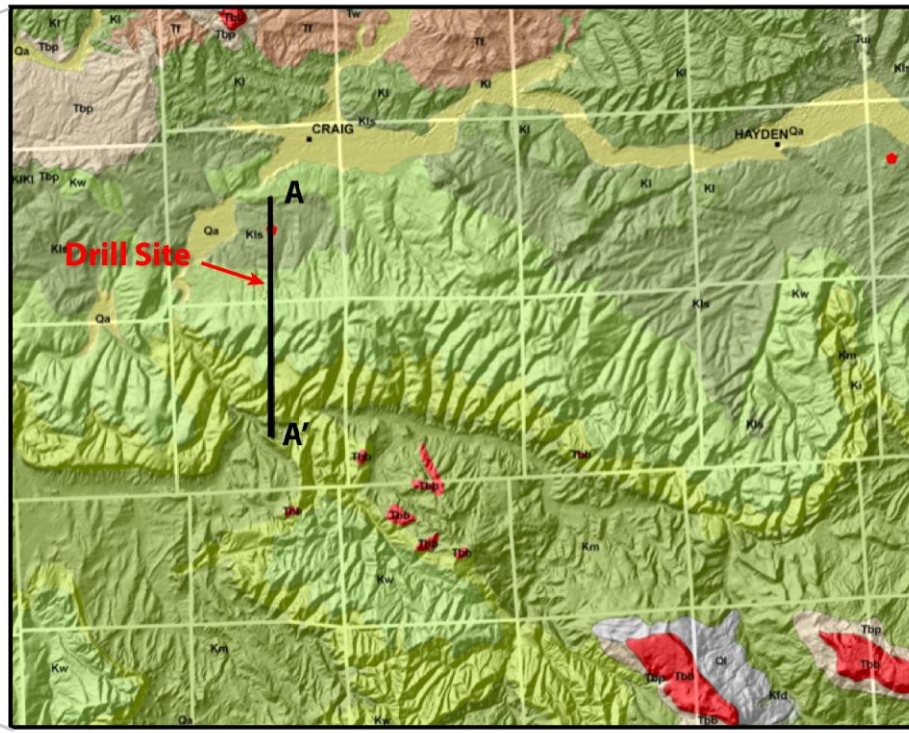
Progress so far:

- Database in place and evolving
- Existing seismic lines purchased
- Processing & interpreting seismic underway
- Mapping of structure underway
- New VSP lines being designed and planned
- Location for drill hole picked
- Permitting of well to begin ASAP

Progress to Date: Craig, Colorado Site

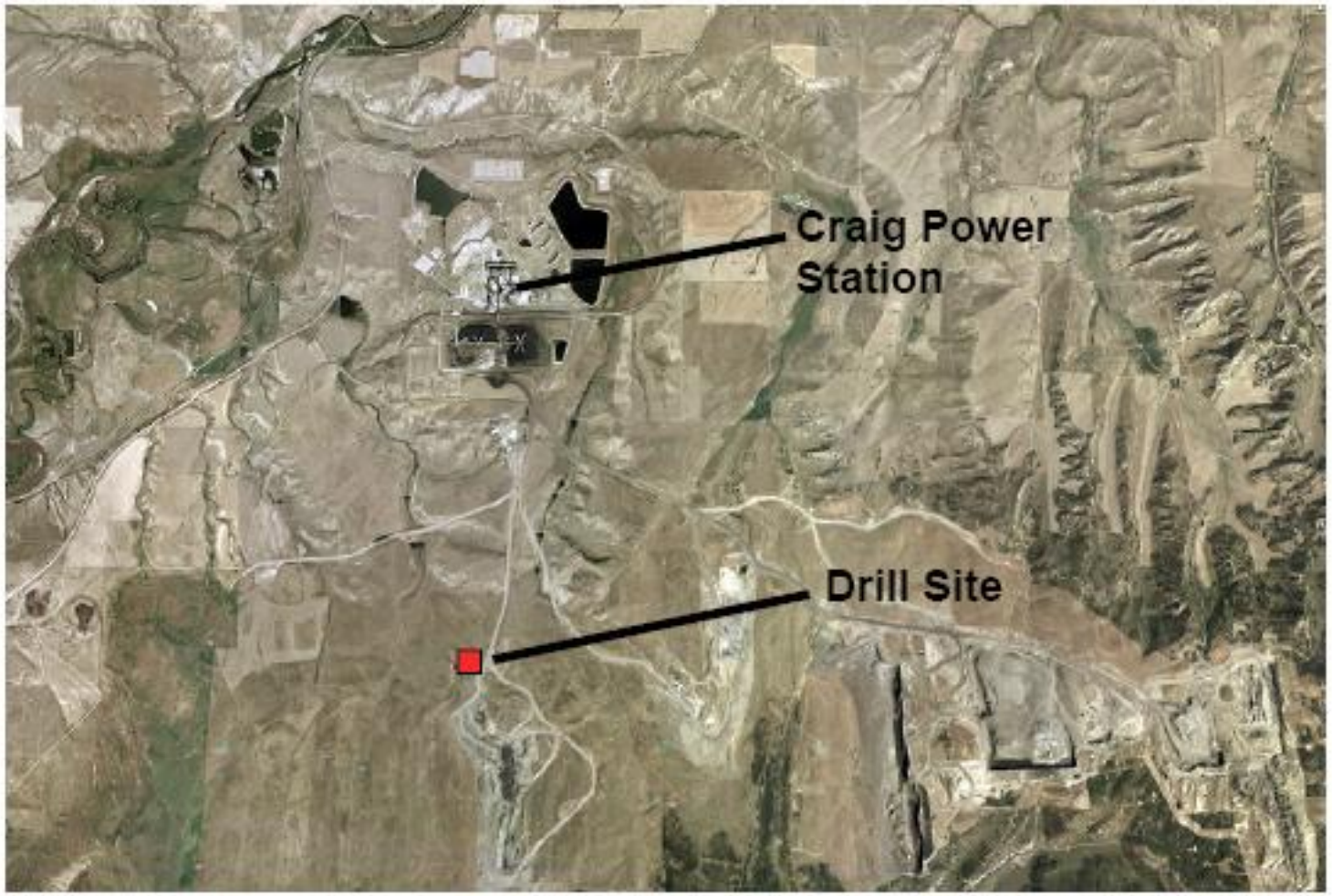
Tentative drill sites and VSP transects picked





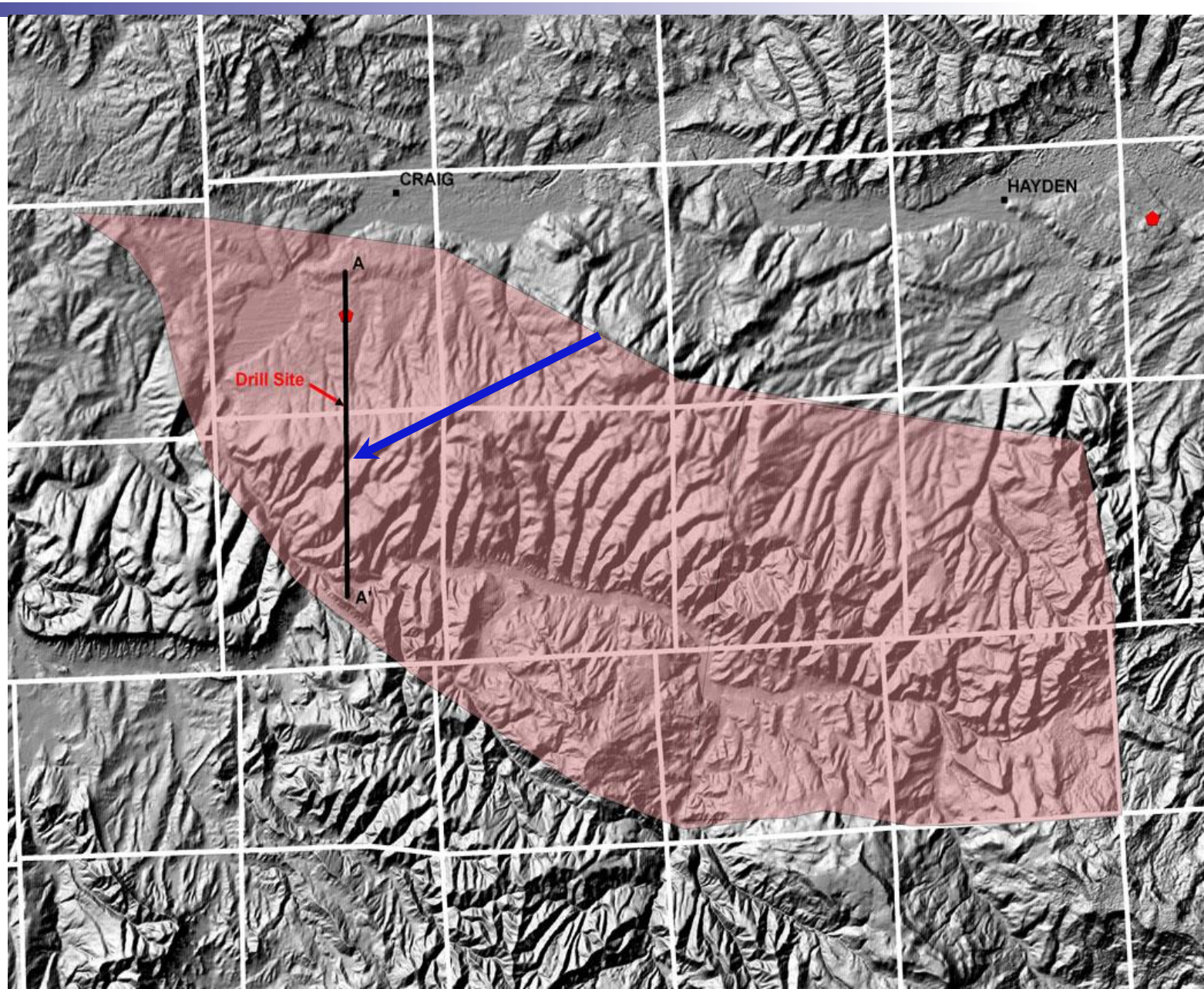
Progress to Date: Craig, Colorado Site

Tentative drill sites and VSP transects picked

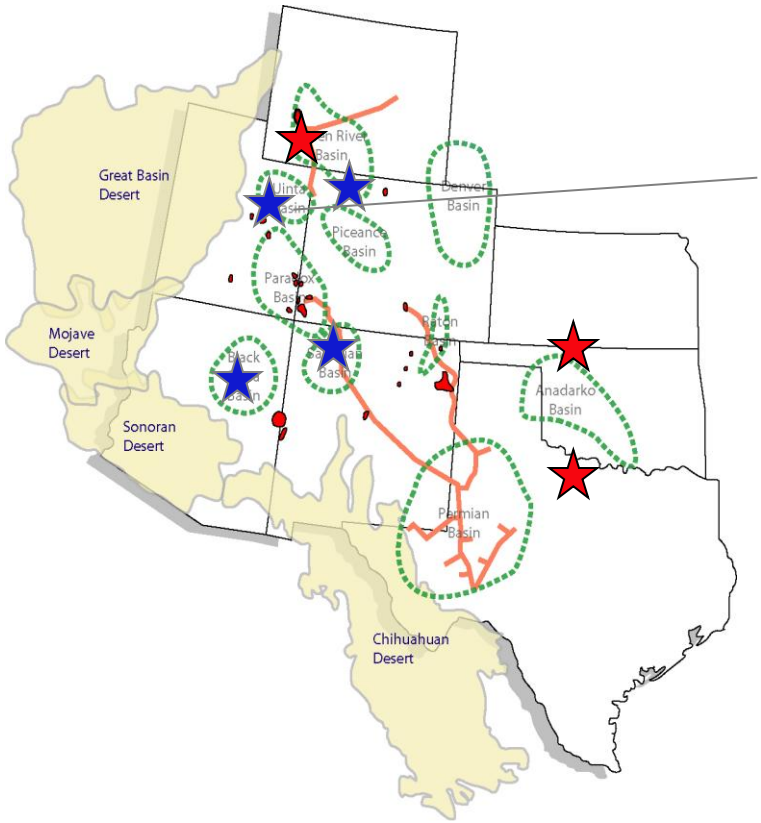


Progress to Date: Craig, Colorado Site

We also picked tentative VSP transects to evaluate



Progress to Date: Uinta Basin, Utah



(1) Colorado - Laramide Structure at Craig

(2) Utah - Uinta Basin Area

Progress to Date: Uinta Basin, Utah

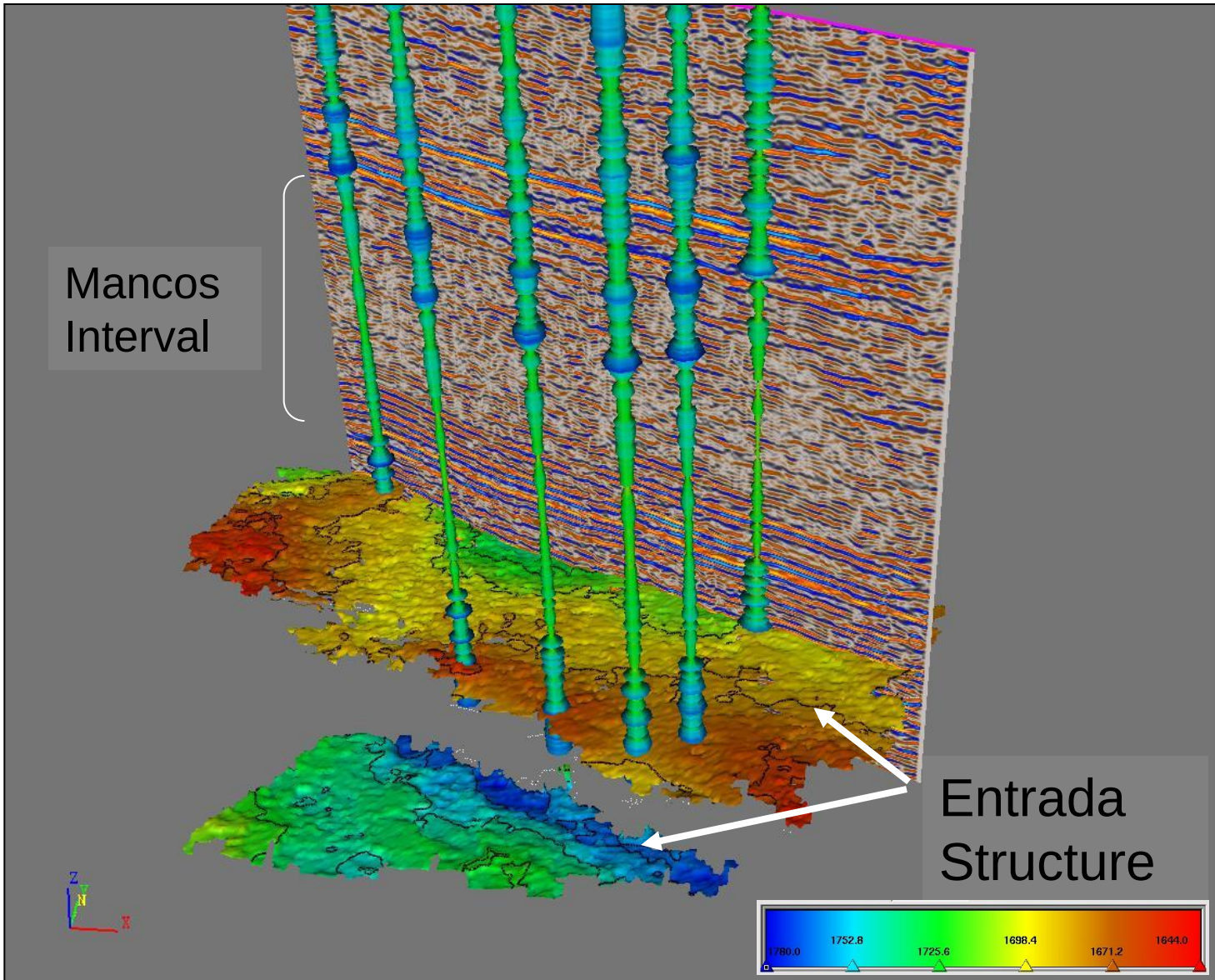
Outcrop Data Collected

Period	Formation / Member		Thickness (feet)	Lith.
CRET	Mancos Shale	Blue Gate Sh	4800	
		Frontier Ss	100	
		Mowry Shale	30	
	Dakota Sandstone		75	
	Cedar Mtn Fm	Upper member	75	
		Buckhorn Cg Mbr	40	
JURASSIC	Morrison Formation		600	
	Curtis / Summerville		100	
	Entrada Formation		130	
	Carmel Formation		70	
	Navajo Sandstone		650	
TRIASSIC	Chinle Fm	Upper member	150	
		Gartra Grit Mbr	60	
	Moenkopi Fm		500	
PERM	Park City Fm		150	
PENN	Weber Sandstone		900	

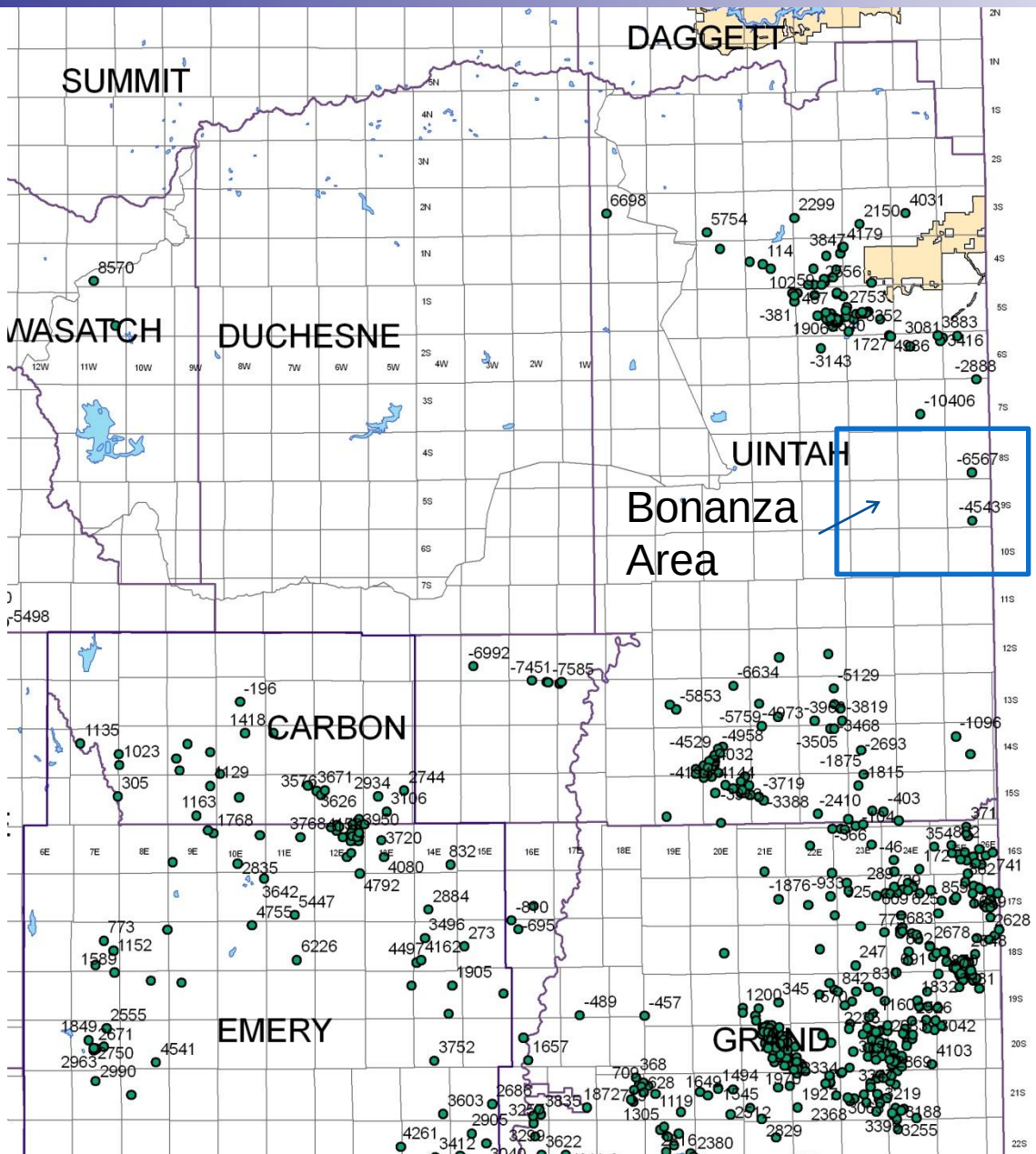
Seal Reservoir

Progress to Date: Uinta Basin, Utah

Log and other well data collected



Progress to Date: Uinta Basin, Utah

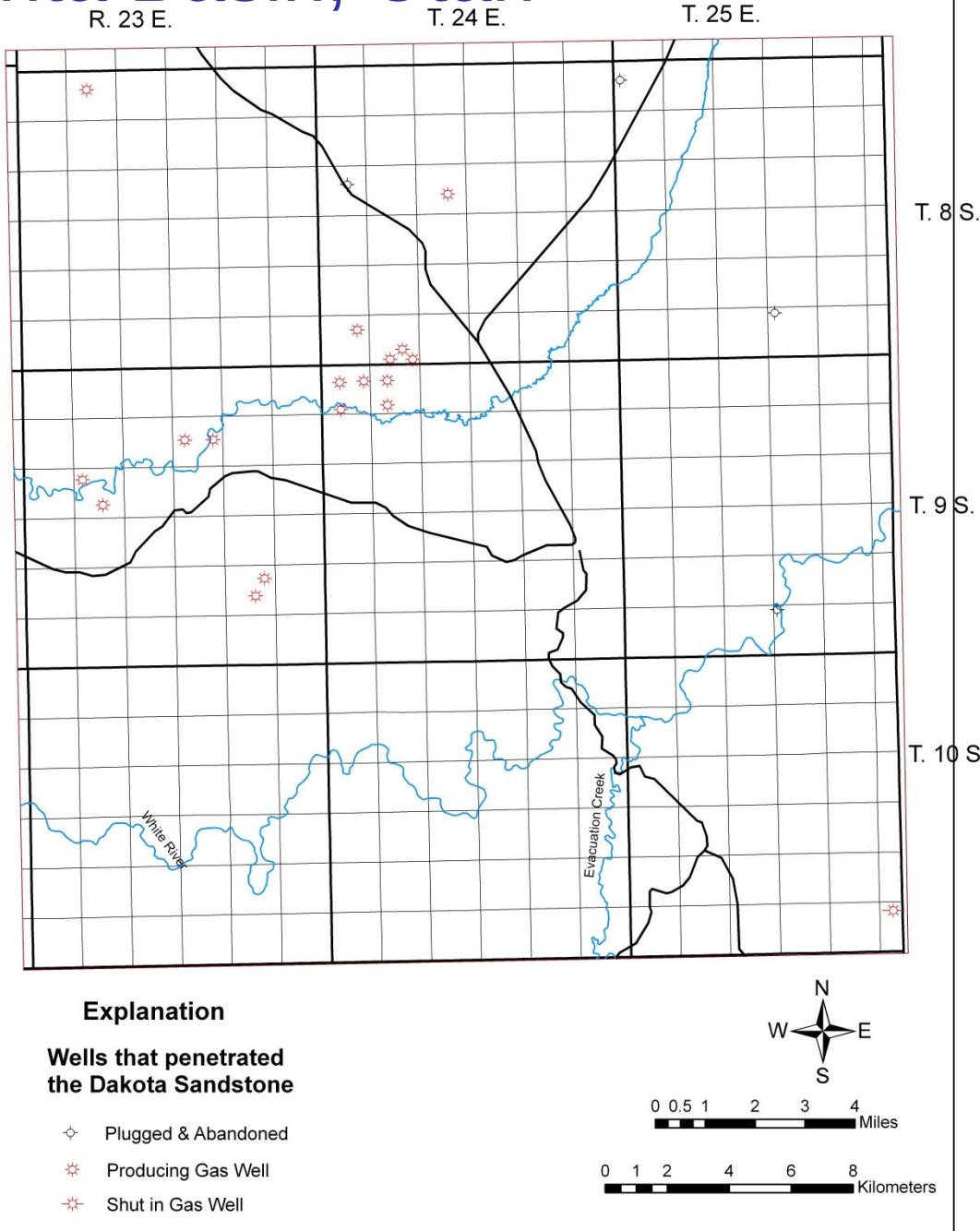


Maps Constructed And Sites Compared

Uinta Basin, Utah and Bonanza area Wells penetrating Entrada Sandstone

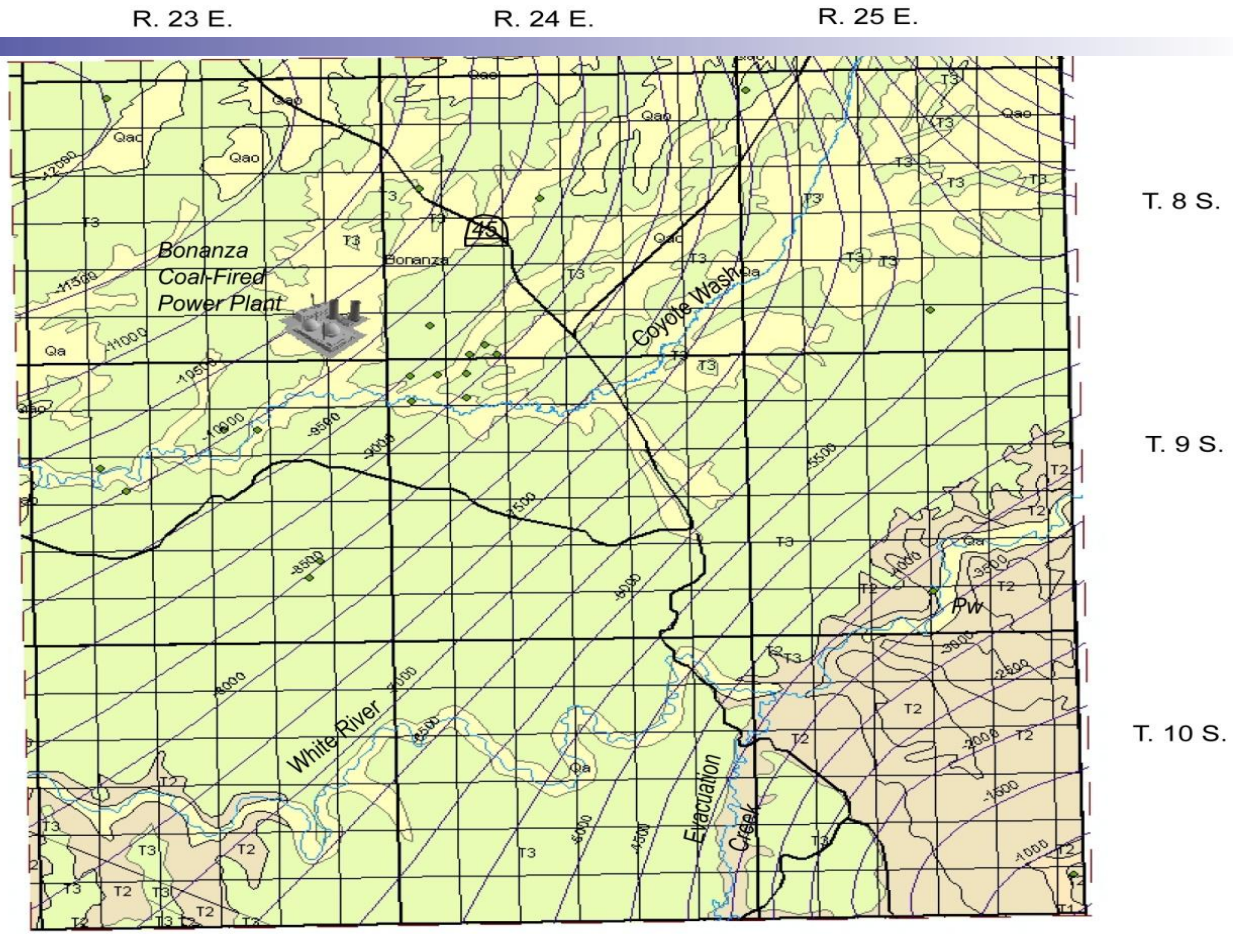
Progress to Date: Uinta Basin, Utah

Maps Constructed And Sites Compared



Progress to Date: Uinta Basin, Utah

Maps Constructed And Sites Compared



Bonanza area, Uintah County, Utah

Geologic map

Qa and Qao	Quaternary
T3	Uinta Formation
T2	Green River Formation

Green circles are wells that have penetrated the Cretaceous Dakota Sandstone.
Pw is the Watson well which reached a total depth in the Pennsylvanian Weber Sandstone.

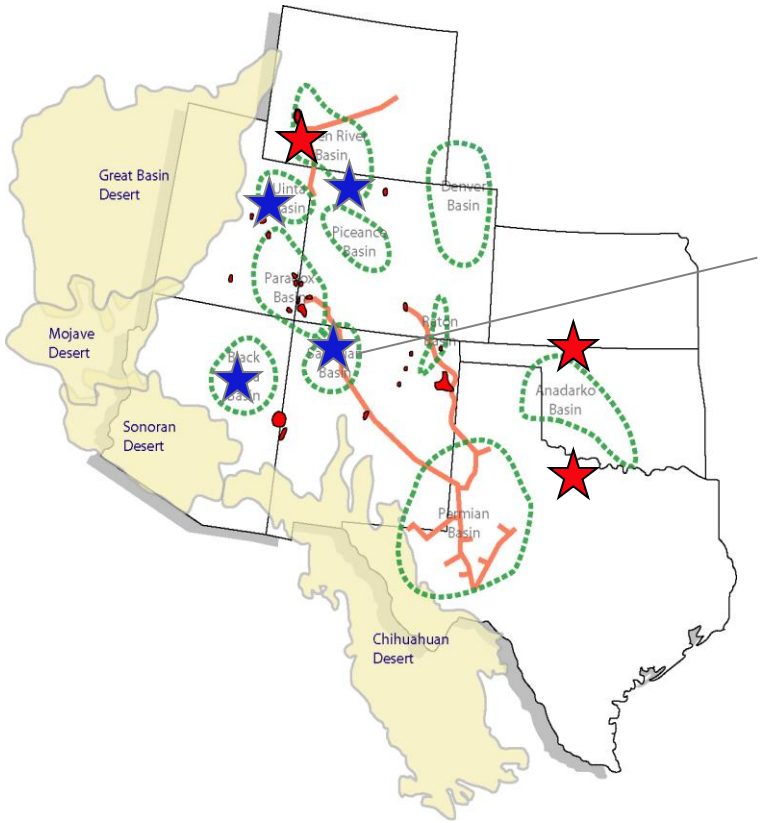
Structure contours are top of Dakota Sandstone, mean sea level, contour interval 500 feet, from USGS Resource Assessment.

Progress to Date: Uinta Basin, Utah

Top two local sites picked for assessment:

Rank	Location	Area	Depth (ft): Kd Je Pw other	Thickness (ft): Kd Je Pw other	Porosity	Status	Land	Resource: Power plant Coal Rail	Pressure (psi) Calc. @ .45psi/ft	Temp (^{0}F) Calc. @ 60+1F/ 100 ft	Storage Estimate Million Metric tons
X	Cisco Dome 19S-20S 21E-22E	24 sq mi 13,440 acres	Kd 2000 Je 2822 Jn 3500 Pw NA	Kd 60 Je 400 Jn 300	Kd 15% Je 18% Jn 12%	Prod Kd-Jm Je abd Jn non-productive	BLM	75 mi. from Castle Dale. Next to undeveloped coal, rail and freeway access.	Kd 900 Je 1300 Jn 1600	Kd 80 Je 90 Jn 95	Je 6.4 Jn 13.7 TOTAL 20.1
2	Woodside Dome 19S 13E-14E	40 sq mi. 126,720 aces	Kd NA Je –Jn TS Pwr 3000 Mm 6400	Pwr 450 Mm 700	Pwr 6-8% Mm 2-10%	SI well BBC	BLM	30 mi from Castle Dale. Good access	Pwr 1300 Mm 2900	Pwr 95 Mm 120	Pwr 26.1 Mm 27.2 TOTAL 53.3
X	Summit SRS 19S 11E-12E & all SRS	1300 sq mi. 6,864,000 acres	Pwr outcrops Mm 4100	Mm 700		Non-productive	Location is SITLA Potential is BLM with lots of WSA	20 mi from Castle Dale. Good access	Mm 1800	Mm 100	Mm 716.2 No Kd, Je or Pw
1	Bonanza 9S-10S 24E-25E	100 mi 528,000 acres Potentially much larger	Kd 11,000 Je 12,000 Jn 12,250 Pw 13,800	Kd 80 Je 150 Jn 600 Pw 200	Kd 15% Je 12% Jn 10% Pw 10%	Gas wells Tw-Kd Natural Buttes area Very active gas drilling	BLM, SITLA	Within 6 mi. of Bonanza Power Plant Remote location	Kd 5000 Je 5400 Jn 5500 Pw 6200	Kd 170 Je 180 Jn 180 Pw 200	Kd 30.2 Je 45.3 Jn 151.9 Pw 50.3 TOTAL 277.7
4	Peters Point 12S -13S 15E-17E	30 sq mi. 158,400 acres	Kd 13,000 Je 13,970 Jn 14,578 Pw 16,088 Mm 16,615	Kd 30 Je 80 Jn 50 Pw 320 Mm 600	Kd 10% Je 6% Jn 8% Pw 6% Mm 6%	Tertiary-Jn Very active field	BLM- BBC lease.	Remote location 40 mi from Castle Dale	Kd 5900 Je 6300 Jn 6500 Pw 7200 Mm 7500	Kd 190 Je 200 Jn 200 Pw 220 Mm 230	Kd 2.3 Je 3.6 Jn 3.1 Pw 14.6 Mm 27.3 TOTAL 50.9
X	Gordon Creek 14S 7E-8E	8320 acres	Kd 4025 Je 6400 Jn 8400 Pwr 11,150	Kd 50 Je 270 Jn 350 Pwr 500 ft	Kd 6% Je silt & sh 2-4% Jn 16% Pwr 0-4%	Kf prod. SWP site	mix	High Plateau 20 mi from Castle dale SWP demo site	Kd 1800 Je 2900 Jn 3800 Pwr 5000	Kd 100 Je 125 Jn 140 Pwr 170	Kd 0.8 Je 1.7 Jn 18.3 Pwr 3.3 TOTAL 24.1
X	Green River south 21S 17E-17E	12 sq mi 63,360 acres	Kd-Jn TS Pwr 3000 Mm 10,000	Pwr 260 Mm 400+	Pwr 6-16% Mm 2-6%	Non-productive	BLM, military, SITLA	Next to I-70 and railline 36 mi from Castle Dale 20 mi from undeveloped coal	Pwr 1400 Mm 4500	Pwr 90 Mm 160	Pwr 3.2 Mm 4.8 TOTAL 8.0
3	Last Chance 26S 7E	24 sq mi 126,720 acres	Kd-Jn TS Pwr 3050 Mm 4600	Pwr 150 Mm 900	Pwr 14% (30 ft) Mm 16%	SI gas wells Moenkopi	BLM, SITLA, part WSA	90 mi south of Castle Dale. Remote location	Pwr 1400 Mm 2000	Pwr 90 Mm 105	Pwr 1.3 Mm 80.4 TOTAL 81.7

Progress to Date: New Mexico



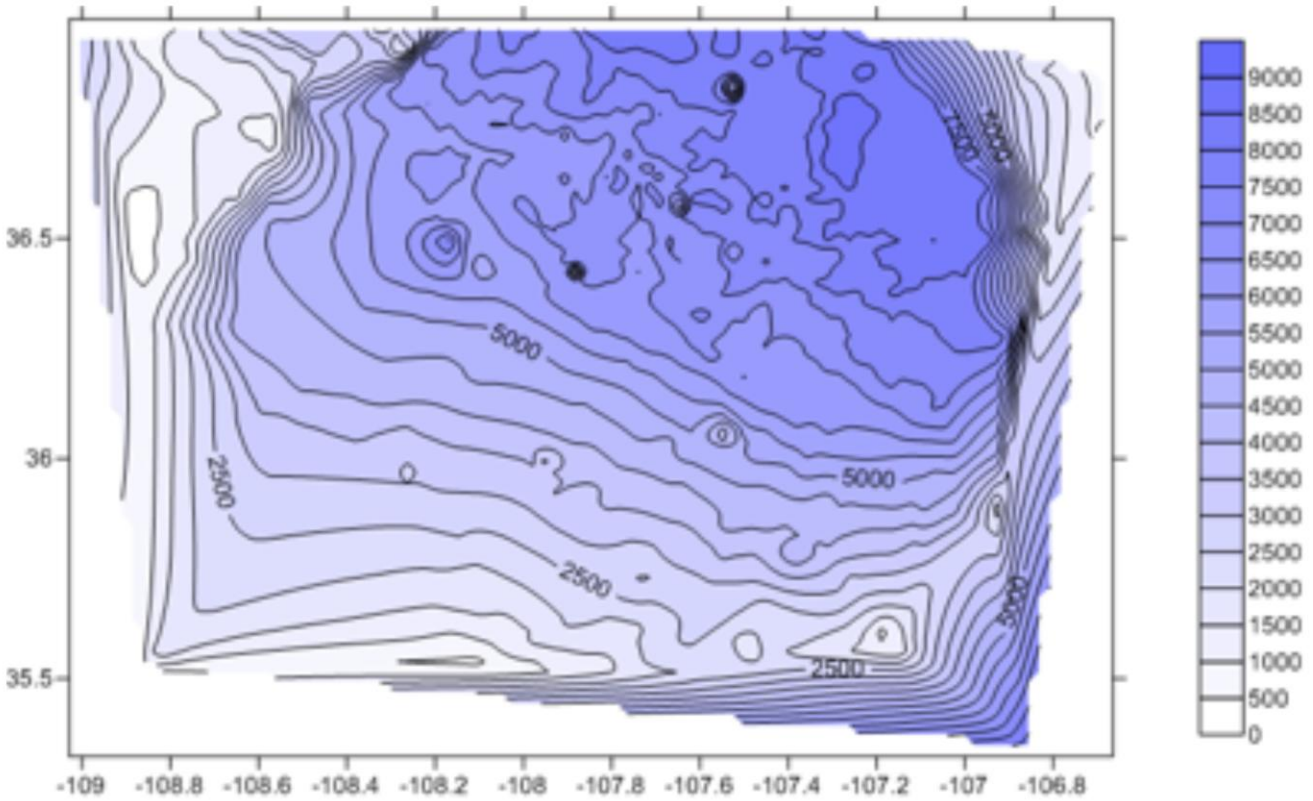
(1) Colorado - Laramide Structure at Craig

(2) Utah - Uinta Basin Area

(3) New Mexico - San Juan Basin Area

Progress to Date: New Mexico

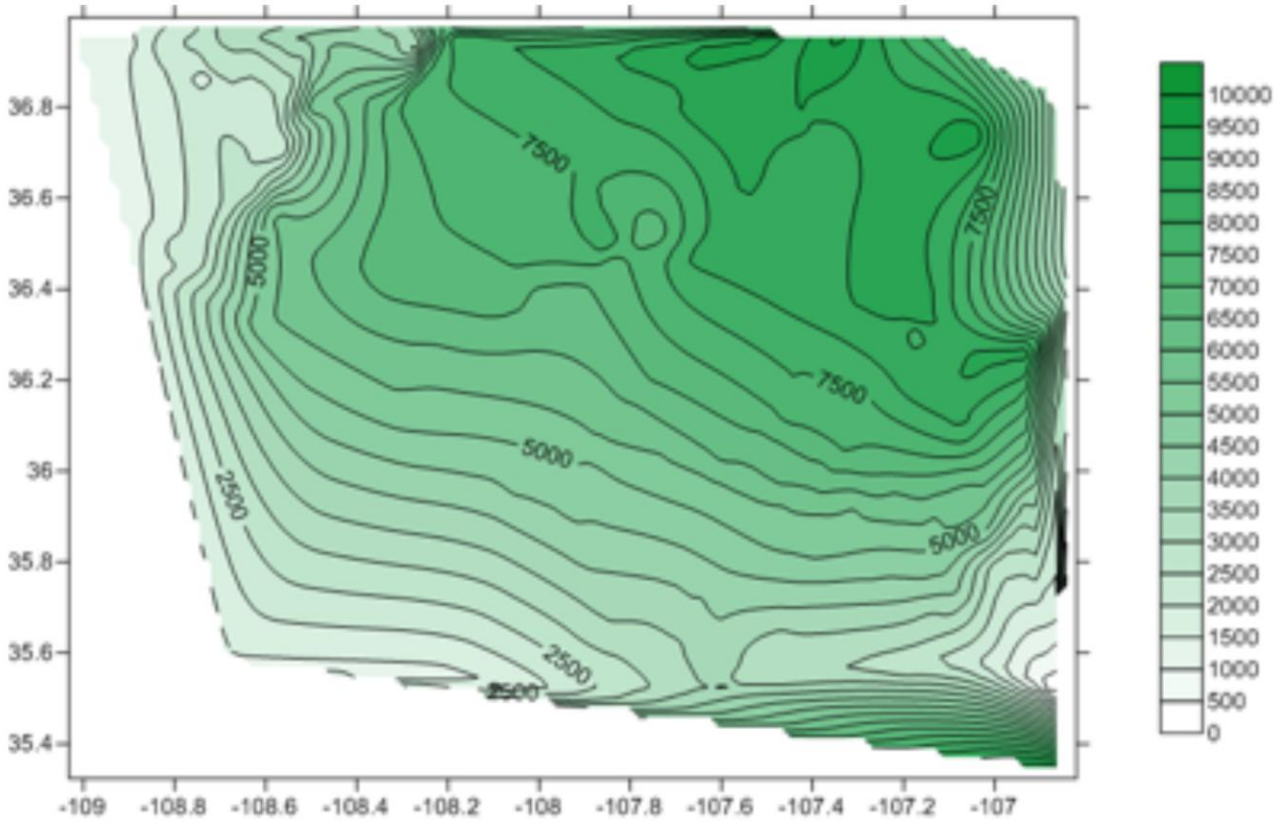
Using available well data, subsurface map of the three formations under development:



Structure-contour map of Dakota SS, San Juan Basin

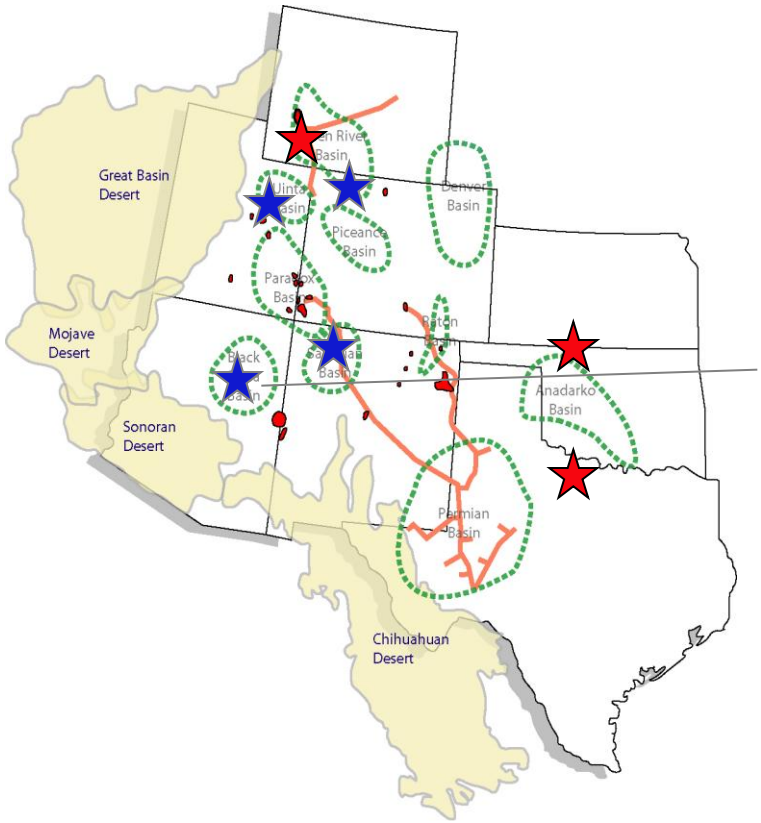
Progress to Date: New Mexico

Using available well data, subsurface map of the three formations under development:



Structure-contour map of Entrada SS, San Juan Basin

Progress to Date: Arizona



(1) Colorado - Laramide Structure at Craig

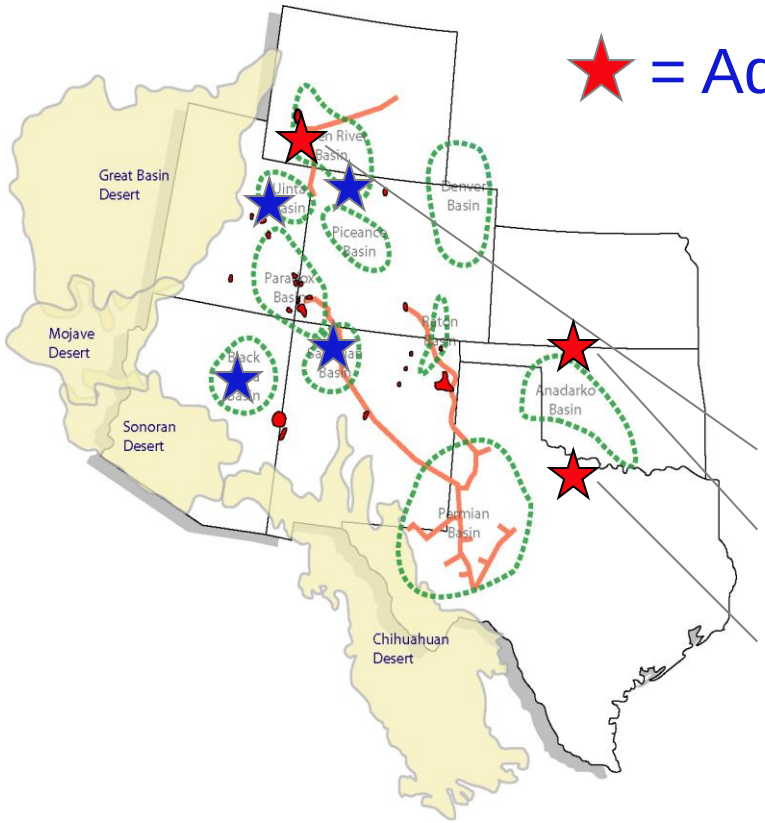
(2) Utah - Uinta Basin Area

(3) New Mexico - San Juan Basin Area

(4) Arizona - Black Mesa Basin

Arizona work not started.

Progress to Date: Wyoming, Kansas, Oklahoma and Texas



★ = Adjacent ARRA Char. Projects

(5) Wyoming - Rock Springs Uplift (UW)

(6) Kansas and Oklahoma (KGS)

(7) Kansas and Oklahoma (BEG)

Presentation Outline

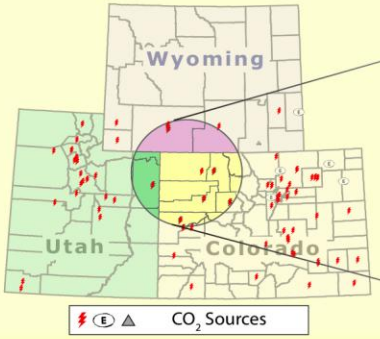
- Project Team (Who)
- Major Goals (Why)
- Work Plan (How)
- Progress to Date (What)
- Project Summary

Project Summary

1.0 Project Management (Plan, Organize, Meetings, Finanacials, Prog. Risk, Outreach/Eduction, Permitting)

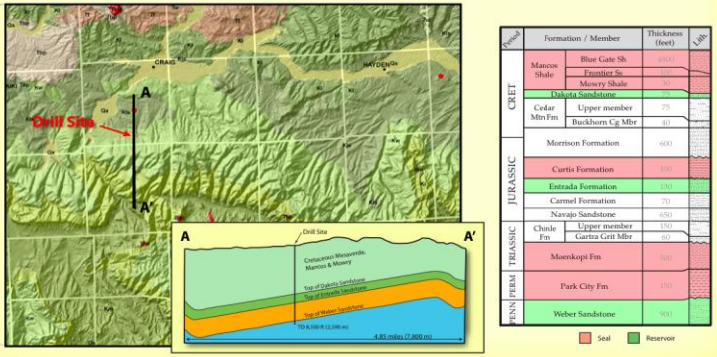
2.0 Regional Significance of Dakota, Entrada & Weber

Review available data (logs, studies, seismic) to determine capacity and injectivity (sustain 30 MMT of CO_2)



3.0 Site Specific Evaluation of Dakota, Entrada & Weber

Conduct field operations (drill/core well, fluid analyses). Use lab and field data to refine capacity, injectivity and containment.



4.0 Conduct Risk Assessment

Create risk registry, identify site-specific FEPs, evaluate mitigatation strategies and any cost-savings.

5.0 Develop Site Selection Criteria

Compile list of selection criteria based upon site-specific characterization results

6.0 Well bore management

Use data from Task 4.0 to prepare a management plan that will prevent leakage of CO_2 through artificial penetrations (well bores, mines, etc).

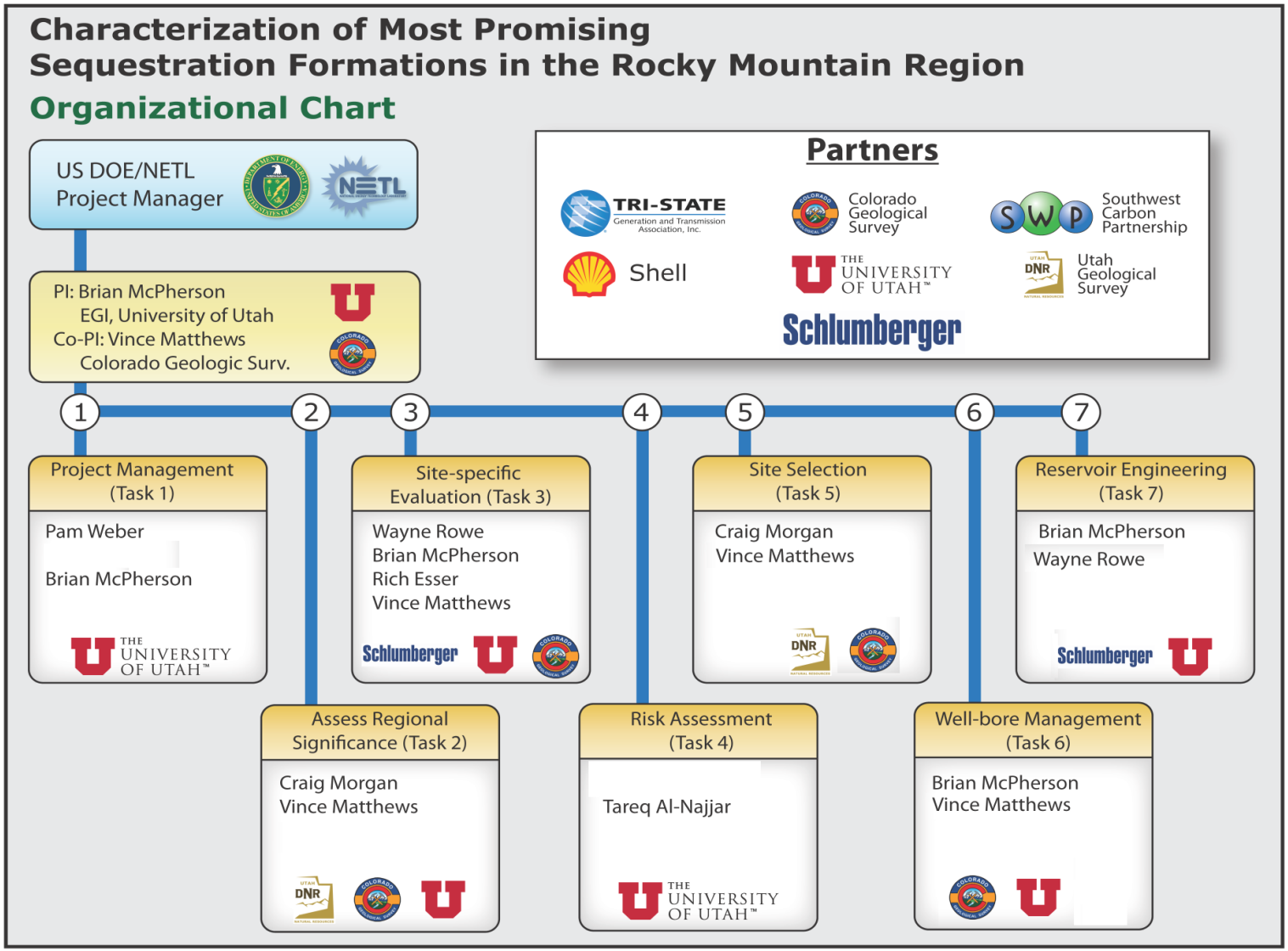
7.0 Maximize CO_2 Injection & Uses of Produced Fluids

Develop an engineering plan to optimize well placement for the region to maximize the amount of CO_2 storage based upon results of the characterization study. Develop a produced fluid disposal plan that will integrate mitigation strategies with respect to reservoir pressure stabilization.

TRI-STATE Generation and Transmission Association, Inc. · The University of Utah · Shell · SWP · Colorado Geological Survey · New Mexico Bureau of Geology · Utah Geological Survey · Arizona Geological Survey · Schlumberger

“Hip pocket” slides for Q&A

Project Team and Approach



Progress to Date: Craig, Colorado Site

Land ownership will support project options and flexibility